High Temperature Materials
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Optical, Thermoradiative, Thermophysical, and Mechanical Properties of Silicon

Ronald H. Bogaard and David L. Taylor

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Part 2

August 1994

High Temperature Materials Information Analysis Center

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13. ABSTRACT *(Maximum 200 words)*

This report presents numerical data and technical information on the properties of pure silicon and doped silicon materials. Materials comprise a variety of doped silicon materials, having both n-type and p-type conduction. Property coverage includes optical (absorption coefficient and refractive index), thermoradiative (normal spectral reflectance, angular spectral reflectance, normal spectral emittance, and normal spectral transmittance), thermophysical (thermal conductivity, specific heat, thermal expansion, and lattice parameter), and mechanical (elastic constants, stress-strain, yield strength under tensile, compressive, and shear loading, flexural strength, and fracture toughness).

Property data are compiled from scientific and technical literature. The compiled data are scrutinized and evaluated through an established set of selection criteria for semiconductor and infrared window materials, and are analyzed for effects due to composition (purity, dopants, carrier concentration), temperature, and wavelength.

The electronic version of this report as a computerized PC-based database is also available on a diskette for use on personal computers. This electronic version is for efficient data retrieval, manipulation, and application.

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Contract No. DLA900-93-D-5002

HTMIAC Report 25 (Interim)
Part 2

August 1994

HIGH TEMPERATURE MATERIALS INFORMATION ANALYSIS CENTER
(HTMIAC)

Operated by
CENTER FOR INFORMATION AND NUMERICAL DATA ANALYSIS AND SYNTHESIS
(CINDAS)
Purdue University
2595 Yeager Road
West Lafayette, Indiana 47906-1398

PREFACE

"Optical, Thermoradiative, Thermophysical, and Mechanical Properties of Silicon" is being prepared by the High Temperature Materials Information Analysis Center (HTMIAC). It is published at this time as an *interim* report so as to make the evaluated information available early to users in the DoD and DoD-contractor community and to avoid significant delays. The *interim* report will be improved and expanded and the data contained herein will be further analyzed with the aim of republishing it in final format as an authoritative databook.

Property data for silicon that are available in the literature are widely recognized to be sensitive to variations in material related factors. Many issues that are important in determining property behavior of these materials have been brought forward and widely discussed in the literature. Our objective is to bring them together into a single volume and to document the data and supporting information that bear upon the behavior of silicon, in particular the temperature, wavelength, and composition dependence of its properties.

The present compilation of analyzed property data on silicon is part of a continuing effort for the development, expansion, update, and upgrade of the High Temperature Materials Properties (HTMP) Database, a computerized numerical/ technical database containing numerical data and technical information on materials and properties of interest to high temperature materials technologies. The property data compiled are extensively searched from the worldwide scientific and technical literature, subjected to selection criteria established for material property data capture activities at HTMIAC/CINDAS, and evaluated and analyzed on a property basis in order to clarify discordant data issues and to make effects of affecting variables upon property behavior more readily evident to users of the data.

This interim report is organized with major sections according to property groups. Coverage within each property group is incorporated into subsections dealing with the individual properties of the same property group. Each subsection consists of a sequence of individual data sets and accompanying data plot figures for a series of silicon materials including: intrinsic, various dopants, n-type, and p-type. The property sequence listed under each of the property groups is as follows: for optical properties: absorption coefficient and refractive index; for thermoradiative properties: normal spectral reflectance, angular spectral reflectance, normal spectral emittance, and normal spectral transmittance; for thermophysical properties: thermal conductivity, specific heat, thermal expansion, and lattice parameter; and for mechanical properties: elastic constant, stress-strain, yield strength under tensile, compressive, and shear loading, flexural strength, and fracture toughness.

HTMIAC, a DoD Information Analysis Center, is sponsored and administratively managed and funded by the Defense Technical Information Center (DTIC), ATTN: DTIC-AI, Cameron Station, Alexandria, VA 22304-6145, and is under the IACs program management of Dr. Forrest R. Frank. HTMIAC is operated by the Center for Information and Numerical Data Analysis and Synthesis (CINDAS), Purdue University, West Lafayette, Indiana 47906-1398 under Contract DLA900-93-D-5002. The contract was awarded to Purdue by the Defense Electronics Supply Center (DESC), ATTN: DESC-EACC, Dayton, Ohio 45444-5181 with Ms. Cheryl A. Montoney as the Contracting Officer. HTMIAC is under the technical direction and monitoring of the Contracting Officer's Technical Representative (COTR), Mr. Jerome Persh, Senior Specialist for Materials and Structures, Office of the Director of Defense Research and Engineering (Advanced Technology), ATTN: ODDR&E (AT), The Pentagon, Room 3D1089, Washington, DC 20301-3080 and the Technical Coordinator, Mr. Roger E. Rondeau, Air Force Wright Laboratory, ATTN: WL/MLPJ, Wright-Patterson Air Force Base, Ohio 45433-7702.

HTMIAC serves as the DoD's central source of engineering data and technical information on high temperature materials, especially in the critical technology areas of aerospace structural composites and metals, infrared detector materials, and coatings, and the effects of laser irradiation on these materials. It supports the DoD research, development, test, evaluation, engineering, and acquisition programs as well as defense systems and military hardware in general where scientific and technical information (STI) on high temperature materials technologies is required, and supports the laser effects technology communities with laser-materials interaction data as well as high temperature material property data for laser structural and detector susceptibility, vulnerability, survivability, and hardening assessments and studies in particular. Furthermore, HTMIAC supports the Joint Logistics Commanders/ Joint Directors of Laboratories Technology Panel for Advanced Materials (TPAM), and provides assistance to or receives guidance from other Defense programs and groups as designated by the COTR.

This report is credited to the collective efforts of many HTMIAC and/or CINDAS staff members, who contributed to the technical work and/or the preparation of this report. In addition to the authors listed on the cover, P. D. Desai, J. F. Chaney, V. Ramdas, H. H. Li, J. C. F. Chen, and Carol Dwenger also contributed to this report.

C. Y. Ho
Director
HTMIAC and CINDAS

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Part 2

2.5. Mechanical Properties

MATERIAL: Silicon: P doped

PROPERTY: Elastic Constant, C(11)

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PURDUE UNIVERSITY
DATA SET 97

****

Composition

2.0e19	cm^{-3}	Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :

Specimens prepared from Lopex-grade silicon.

Specimen Identification

Dimensions (Geometry) :

Length	1.5	cm
Width	1.5	cm
Thickness	1.5	cm

Additional Properties

Density Initial/Final (295K) :

	2.3297	$g\ cm^{-3}$

Additional Properties

Carrier/Impurity Conc. :		
Dislocation Density	500.	cm^{-2}
Temperature	298.	K
Electrical Properties :		
Electrical Resistivity	3.26e-05	Ω m
Temperature	298.	K

Other Properties-Textual :

Carrier density was from Hall effect measurement.

Measurement/Evaluation Method

Name/Description :

Velocity of Sound Method
Sound velocities determined by a pulse-echo technique.
Radio frequency pulses of 12., 36., or 60. MHz were used .

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(11)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	1.638e+11	smoothed data

2.000e+01	1.639e+11
4.000e+01	1.640e+11
6.000e+01	1.641e+11
8.000e+01	1.642e+11
1.000e+02	1.643e+11
1.200e+02	1.644e+11
1.400e+02	1.644e+11
1.600e+02	1.644e+11
1.800e+02	1.644e+11
2.000e+02	1.644e+11
2.200e+02	1.644e+11
2.400e+02	1.643e+11
2.600e+02	1.642e+11
2.800e+02	1.641e+11
3.000e+02	1.640e+11
3.200e+02	1.638e+11

Comments on Data

Data read from figure. Uncertainty is within +/- 1.0 pct.

Reference

ELECTRONIC EFFECTS IN THE ELASTIC CONSTANTS OF n-TYPE SILICON.
Hall, J. J.
PHYS. REV.
161 (3), 756-61, 1967.

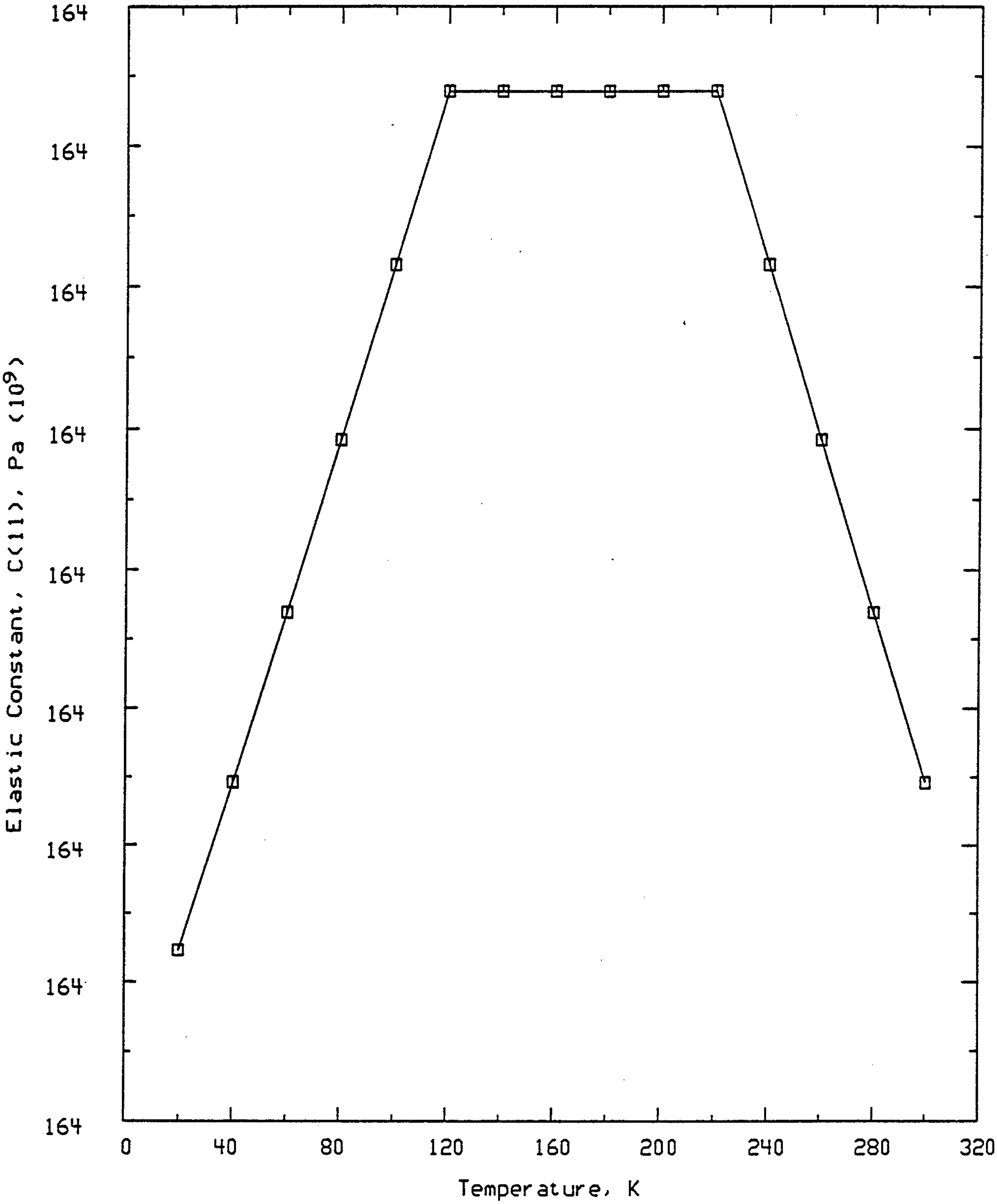

Figure 97 Elastic Constant, C(11) of Silicon: P doped

MATERIAL: Silicon, n-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Elastic Constant, C(11)	DATA SET 98

****

Material Preparation

Crystal Growing Method :

Specimens prepared from Lopex-grade silicon.

Specimen Identification

Dimensions (Geometry) :

Length	1.5	cm
Width	1.5	cm
Thickness	1.5	cm

Additional Properties

Density Initial/Final (295K) :

	2.3290	g cm^{-3}

Additional Properties

Carrier/Impurity Conc. :

Dislocation Density	500.	cm^{-2}
Temperature	298.	K

Electrical Properties :

Electrical Resistivity	150.	10^{-3} Ω cm
Temperature	298.	K

Other Properties-Textual :

Carrier density was from Hall effect measurement.

Measurement/Evaluation Method

Name/Description :

Velocity of Sound Method

Sound velocities determined by a pulse-echo technique.

Radio frequency pulses of 12., 36., or 60. MHz were used .

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(11)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	1.676e+11	smoothed data
2.000e+01	1.676e+11	
4.000e+01	1.676e+11	
6.000e+01	1.675e+11	

8.000e+01	1.675e+11
1.000e+02	1.674e+11
1.200e+02	1.673e+11
1.400e+02	1.672e+11
1.600e+02	1.670e+11
1.800e+02	1.669e+11
2.000e+02	1.667e+11
2.200e+02	1.665e+11
2.400e+02	1.663e+11
2.600e+02	1.661e+11
2.800e+02	1.659e+11
3.000e+02	1.656e+11
3.200e+02	1.654e+11

Comments on Data

Data read from figure. Uncertainty is within +/- 1.0 pct.

Reference

ELECTRONIC EFFECTS IN THE ELASTIC CONSTANTS OF n-TYPE SILICON.
Hall, J. J.
PHYS. REV.
161 (3), 756-61, 1967.

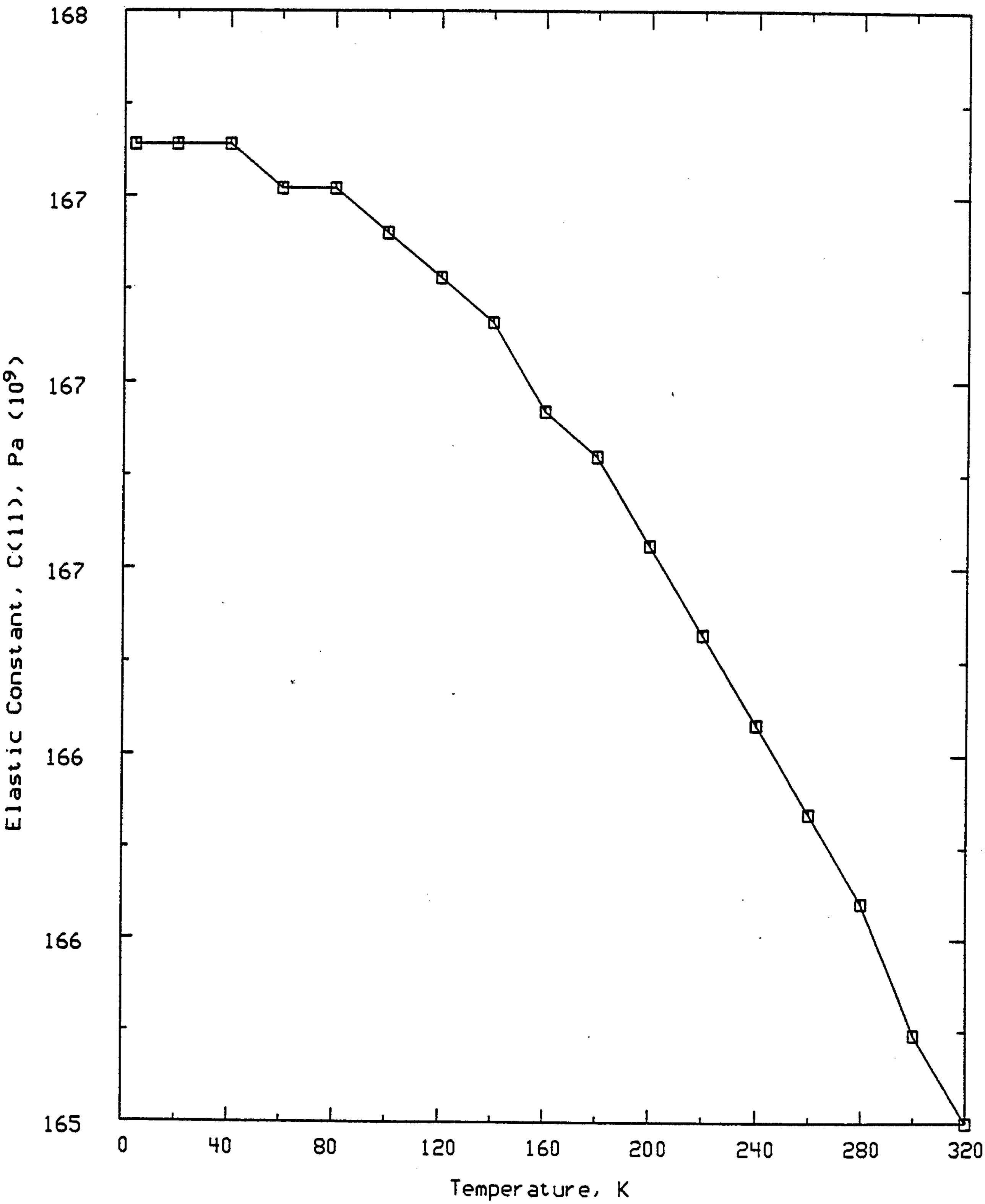

Figure 98. Elastic Constant, C(11) of Silicon, n-type

MATERIAL: Silicon, p-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Elastic Constant, C(11)	DATA SET 99

****

Composition

99.993	weight percent	Silicon
10	ppm atomic	Aluminum
<2	ppm atomic	Boron
<3	ppm atomic	Chromium
20	ppm atomic	Copper
25	ppm atomic	Iron
<3	ppm atomic	Magnesium
3	ppm atomic	Manganese
<3	ppm atomic	Nickel
<0.5	ppm atomic	Silver

Specimen Identification

Dimensions (Geometry) :

Length	25.0	mm
Diameter	25.0	mm

Additional Properties

Density Initial/Final (295K) :

	2.329	g cm^{-3}

Additional Properties

Electrical Properties :

Electrical Resistivity	0.22	Ω cm
Temperature	298.	K
Hole Concentration	4.8e16	cm^{-3}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Pulse-Echo Sound Velocity Technique
Elastic constants calculated from the measured velocities through the single crystal.

Parameters-Textual :

Frequency was 30 MHz with 1.5 kHz band

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(11)	Pa

Data Points :

X	Y
2.980e+02	1.652e+11
3.230e+02	1.650e+11
3.480e+02	1.646e+11
3.680e+02	1.644e+11
3.980e+02	1.640e+11
4.230e+02	1.637e+11
4.480e+02	1.633e+11
4.730e+02	1.630e+11
4.980e+02	1.627e+11
5.330e+02	1.622e+11
5.730e+02	1.616e+11
6.130e+02	1.611e+11
6.530e+02	1.605e+11
6.730e+02	1.602e+11
6.980e+02	1.599e+11
7.280e+02	1.594e+11
7.580e+02	1.590e+11
7.880e+02	1.586e+11
8.180e+02	1.582e+11
8.530e+02	1.577e+11
9.030e+02	1.570e+11
9.530e+02	1.563e+11
1.003e+03	1.555e+11
1.053e+03	1.547e+11
1.103e+03	1.539e+11

Comments on Data

Uncertainty in RT C11 value is +/- 1.32, data calculated from Table III.

Reference

USE OF THE IMPULSE METHOD FOR MEASURING THE ELASTIC CONSTANTS OF SOLIDS AT HIGH TEMPERATURES. APPLICATION TO SINGLE-CRYSTAL SILICON.
Ezz-El-Arab, M. A.
ANN. PHYS. (PARIS)
7 (3), 133-58, 1972.

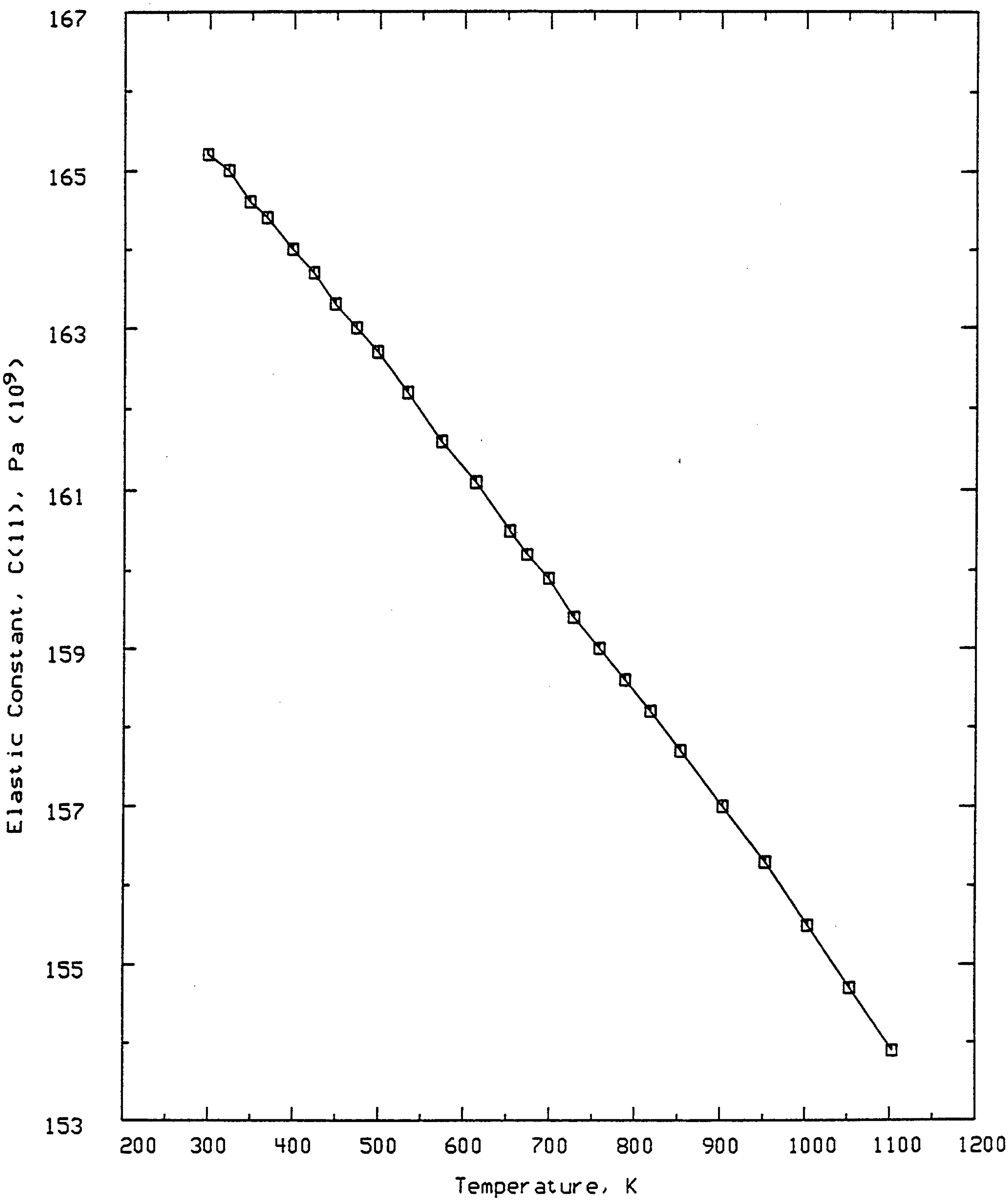

Figure 99 Elastic Constant, C(11) of Silicon, p-type

MATERIAL: Silicon, p-type

PROPERTY: Elastic Constant, C(11)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 100

****

Specimen Identification

Dimensions (Geometry) :

Length	20.	mm
Thickness	4.	mm
Width	4.	mm

Additional Properties

Density Initial/Final (295K) :

	2.33	g cm^{-3}

Additional Properties

Electrical Properties :

Electrical Resistivity	420.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Resonance-Frequency Sound Velocity Technique
Resonance frequencies ranged from 127 to 280 kHz.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :

Pressure	1.e-04	mmHg

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(11)	Pa

Data Points :

X	Y
0.000e+00	1.660e+11
2.930e+02	1.601e+11
3.730e+02	1.595e+11
4.730e+02	1.586e+11
5.730e+02	1.573e+11
6.730e+02	1.557e+11
7.730e+02	1.542e+11
8.730e+02	1.527e+11
9.730e+02	1.514e+11

1.073e+03	1.496e+11
1.173e+03	1.475e+11
1.273e+03	1.451e+11
1.690e+03	1.339e+11

Comments on Data

Values at 0. and 1690. K were extrapolated.
Uncertainty is within +/- 0.4 pct. Data read from table.
The natural frequencies were used to deterimine the Young's moduli and the elasticity moduli as a function of temperature were calculated using published thermal expansion values.

Reference

TEMPERATURE DEPENDENCE OF ELASTIC CONSTANTS OF SILICON.
Burenkov, Yu. A. Nikanorov, S. P.
FIZ. TVERD. TELA (LENINGRAD)
16 (5), 1496-8, 1974.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE, 16 (5), 963-4, 1974)

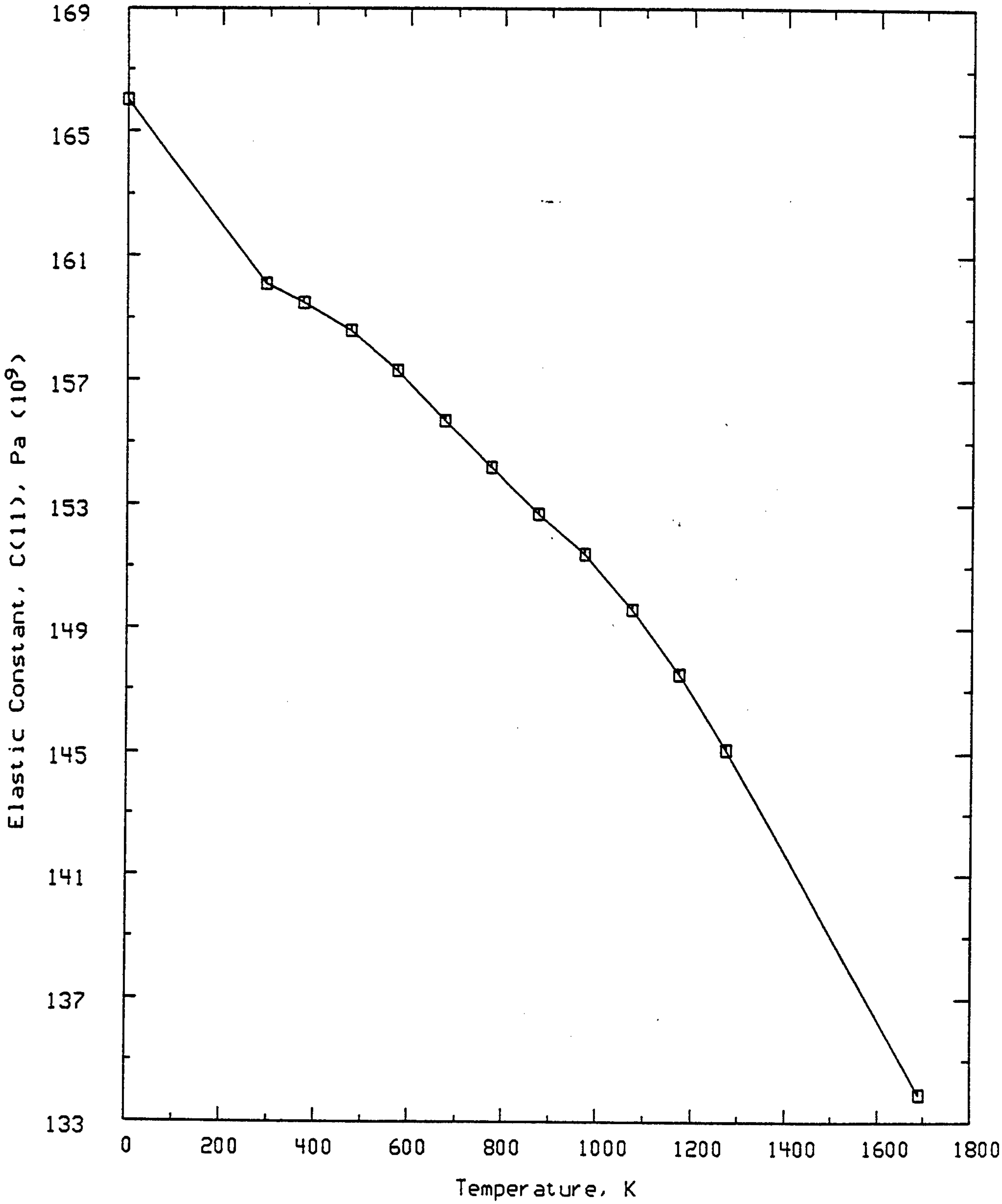

Figure 100 Elastic Constant, C(11) of Silicon, p-type

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(11)

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PURDUE UNIVERSITY
DATA SET 101

****

Specimen Identification

Dimensions (Geometry) :

Length	2.0	cm
Width	1.3	cm

Additional Properties

Density Initial/Final (295K) :

	2.331	g cm^{-3}

Measurement/Evaluation Method

Name/Description :

Single Transducer Sound Velocity Method
Elastic constants calculated from the measured velocities of propagation through the single crystal.

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(11)	Pa

Data Points :

X	Y
7.300e+01	1.675e+11
9.000e+01	1.674e+11
1.000e+02	1.674e+11
1.200e+02	1.673e+11
1.400e+02	1.672e+11
1.600e+02	1.670e+11
1.800e+02	1.669e+11
2.000e+02	1.667e+11
2.400e+02	1.663e+11
2.600e+02	1.661e+11
2.800e+02	1.659e+11
3.000e+02	1.656e+11
3.100e+02	1.655e+11

Comments on Data

smoothed data.

Reference

MEASUREMENT OF ELASTIC CONSTANTS AT LOW TEMPERATURES

BY MEANS OF ULTRASONIC WAVES - DATA FOR SILICON AND
GERMANIUM SINGLE CRYSTALS, AND FOR FUSED SILICA.
McSkimin, H. J.
J. APPL. PHYS.
24 (8), 988-97, 1953.

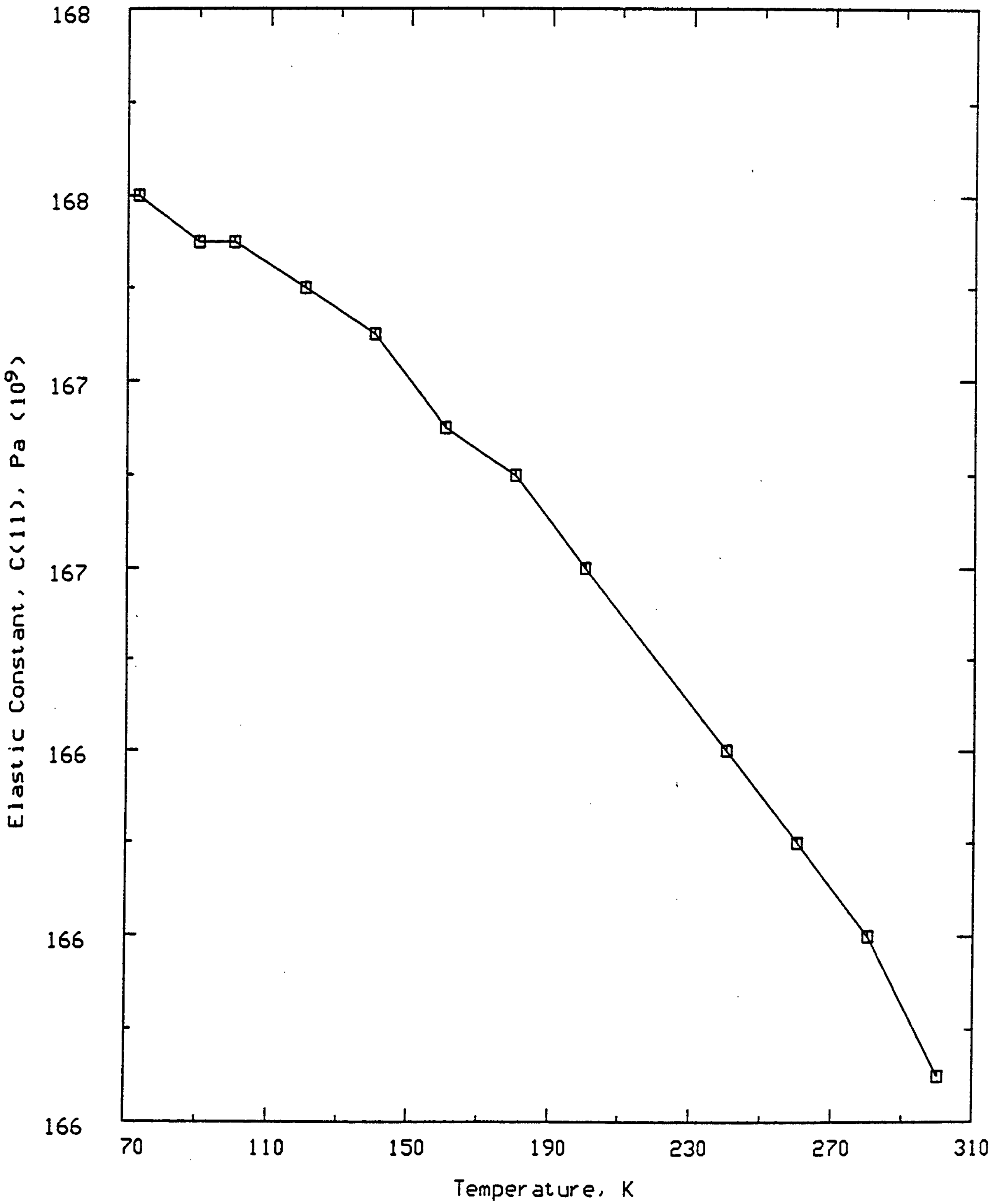

Figure 101 Elastic Constant, C(11) of Silicon

MATERIAL: Silicon: P doped

PROPERTY: Elastic Constant, C(12)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 102

****

Composition

2.0e19 cm^{-3} Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :

Specimens prepared from Lopex-grade silicon.

Specimen Identification

Dimensions (Geometry) :

Length	1.5	cm
Width	1.5	cm
Thickness	1.5	cm

Additional Properties

Density Initial/Final (295K) :

	2.3297	g cm^{-3}

Additional Properties

Carrier/Impurity Conc. :

Dislocation Density	500.	cm^{-2}
Temperature	298.	K

Electrical Properties :

Electrical Resistivity	3.26e-05	Ω m
Temperature	298.	K

Other Properties-Textual :

Carrier density was from Hall effect measurement.

Measurement/Evaluation Method

Name/Description :

Velocity of Sound Method

Sound velocities determined by a pulse-echo technique.

Radio frequency pulses of 12., 36., or 60. MHz were used .

Measured/Evaluated Properties

X : Temperature		K
Y : Elastic Constant, C(12)		Pa

Data Points :

X	Y	Remarks:
4.000e+00	6.694e+10	smoothed data

2.000e+01	6.691e+10
4.000e+01	6.683e+10
6.000e+01	6.672e+10
8.000e+01	6.658e+10
1.000e+02	6.643e+10
1.200e+02	6.625e+10
1.400e+02	6.606e+10
1.600e+02	6.586e+10
1.800e+02	6.567e+10
2.000e+02	6.547e+10
2.200e+02	6.529e+10
2.400e+02	6.512e+10
2.600e+02	6.497e+10
2.800e+02	6.484e+10
3.000e+02	6.475e+10
3.200e+02	6.469e+10

Comments on Data

Data read from figure. Uncertainty is within +/- 1.0 pct.

Reference

ELECTRONIC EFFECTS IN THE ELASTIC CONSTANTS OF n-TYPE SILICON.
Hall, J. J.
PHYS. REV.
161 (3), 756-61, 1967.

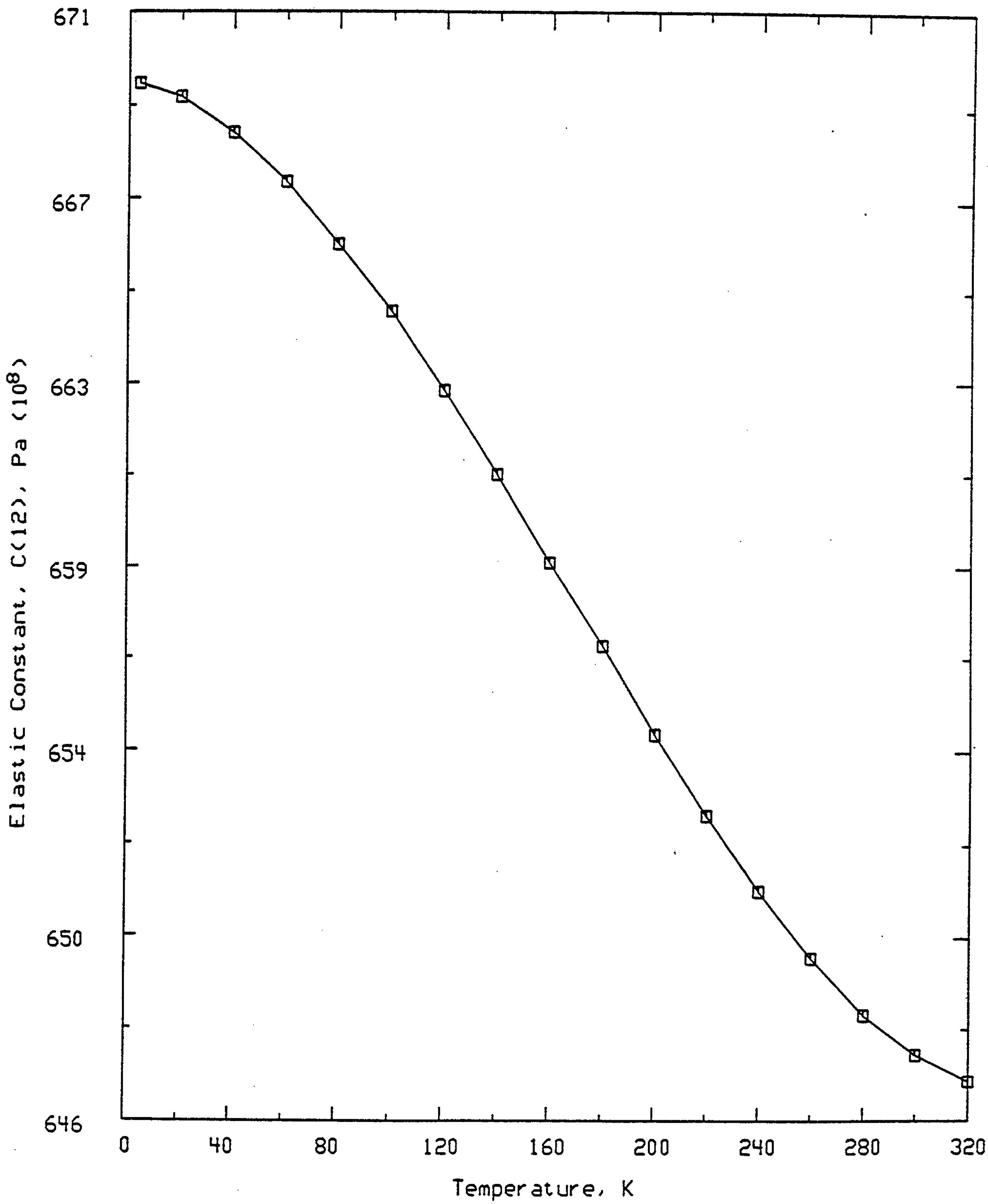

Figure 102 Elastic Constant, C(12) of Silicon: P doped

MATERIAL: Silicon, n-type

PROPERTY: Elastic Constant, C(12)

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PURDUE UNIVERSITY
DATA SET 103

****

Material Preparation

Crystal Growing Method :

Specimens prepared from Lopex-grade silicon.

Specimen Identification

Dimensions (Geometry) :

Length	1.5	cm
Width	1.5	cm
Thickness	1.5	cm

Additional Properties

Density Initial/Final (295K) :

	2.3290	g cm^{-3}

Additional Properties

Carrier/Impurity Conc. :

Dislocation Density	500.	cm^{-2}
Temperature	298.	K

Electrical Properties :

Electrical Resistivity	150.	10^{-3} Ω cm
Temperature	298.	K

Other Properties-Textual :

Carrier density was from Hall effect measurement.

Measurement/Evaluation Method

Name/Description :

Velocity of Sound Method
Sound velocities determined by a pulse-echo technique.
Radio frequency pulses of 12., 36., or 60. MHz were used .

Measured/Evaluated Properties

X : Temperature		K
Y : Elastic Constant, C(12)		Pa

Data Points :

X	Y	Remarks:
4.000e+00	6.502e+10	smoothed data
2.000e+01	6.499e+10	
4.000e+01	6.495e+10	
6.000e+01	6.490e+10	

8.000e+01	6.485e+10
1.000e+02	6.479e+10
1.200e+02	6.472e+10
1.400e+02	6.465e+10
1.600e+02	6.458e+10
1.800e+02	6.450e+10
2.000e+02	6.441e+10
2.200e+02	6.432e+10
2.400e+02	6.422e+10
2.600e+02	6.411e+10
2.800e+02	6.400e+10
3.000e+02	6.388e+10
3.200e+02	6.376e+10

Comments on Data

Data read from figure. Uncertainty is within +/- 1.0 pct.

Reference

ELECTRONIC EFFECTS IN THE ELASTIC CONSTANTS OF n-TYPE SILICON.
Hall, J. J.
PHYS. REV.
161 (3), 756-61, 1967.

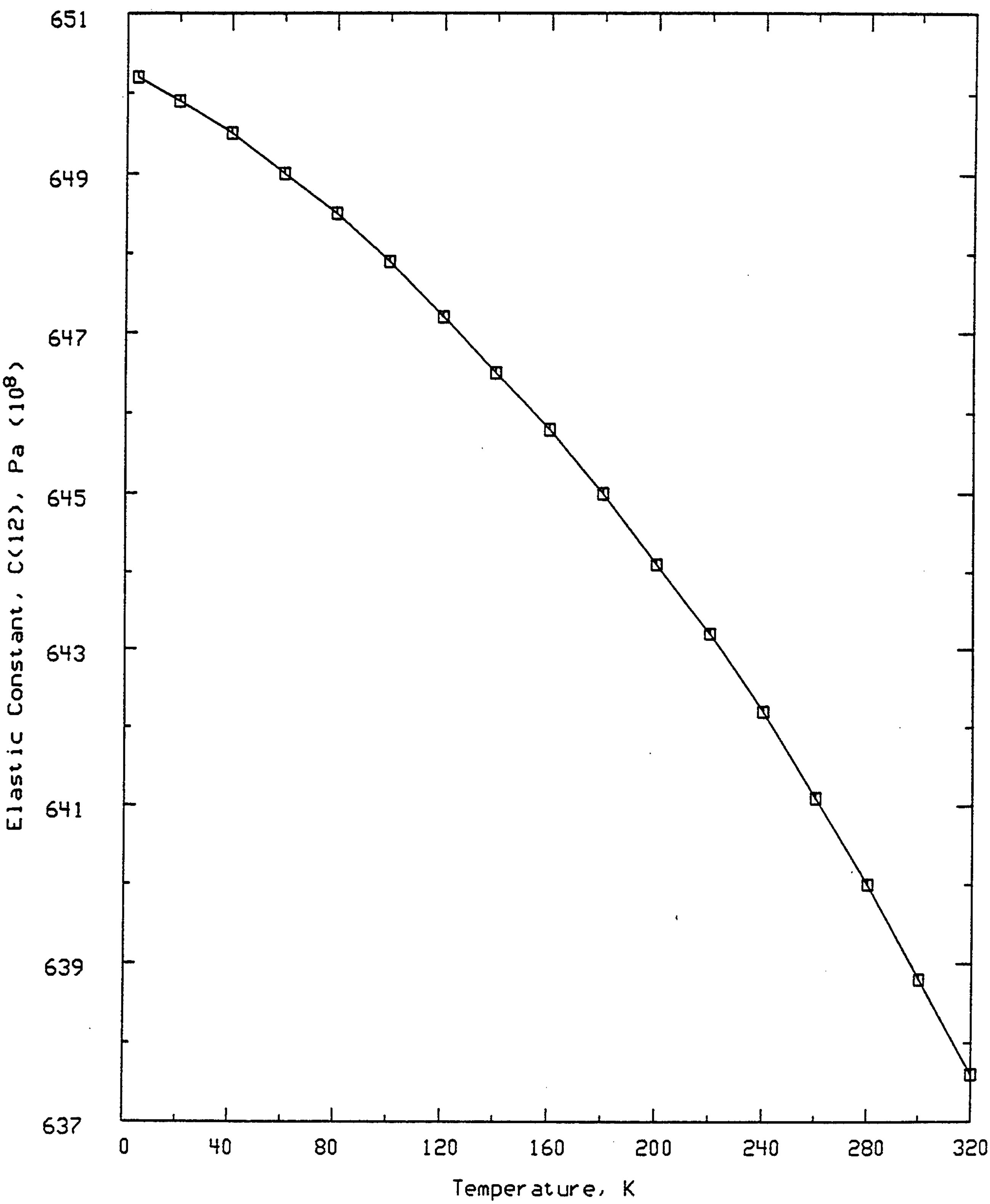

Figure 103 Elastic Constant, C(12) of Silicon, n-type

MATERIAL: Silicon, p-type

PROPERTY: Elastic Constant, C(12)

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PURDUE UNIVERSITY
DATA SET 104

****

Composition

99.993	weight percent	Silicon
10	ppm atomic	Aluminum
<2	ppm atomic	Boron
<3	ppm atomic	Chromium
20	ppm atomic	Copper
25	ppm atomic	Iron
<3	ppm atomic	Magnesium
3	ppm atomic	Manganese
<3	ppm atomic	Nickel
<0.5	ppm atomic	Silver

Specimen Identification

Dimensions (Geometry) :

Length	25.0	mm
Diameter	25.0	mm

Additional Properties

Density Initial/Final (295K) :

	2.329	g cm^{-3}

Additional Properties

Electrical Properties :

Electrical Resistivity	0.22	Ω cm
Temperature	298.	K
Hole Concentration	4.8e16	cm^{-3}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Pulse-Echo Sound Velocity Technique
Elastic constants calculated from the measured velocities through the single crystal.

Parameters-Textual :

Frequency was 30 MHz with 1.5 kHz band

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(12)	Pa

Data Points :

X	Y
2.980e+02	6.390e+10
3.230e+02	6.380e+10
3.480e+02	6.360e+10
3.680e+02	6.350e+10
3.980e+02	6.330e+10
4.230e+02	6.320e+10
4.480e+02	6.300e+10
4.730e+02	6.290e+10
4.980e+02	6.270e+10
5.330e+02	6.250e+10
5.730e+02	6.230e+10
6.130e+02	6.200e+10
6.530e+02	6.180e+10
6.730e+02	6.170e+10
6.980e+02	6.150e+10
7.280e+02	6.130e+10
7.580e+02	6.110e+10
7.880e+02	6.100e+10
8.180e+02	6.080e+10
8.530e+02	6.060e+10
9.030e+02	6.040e+10
9.530e+02	6.010e+10
1.003e+03	6.000e+10
1.053e+03	5.960e+10
1.103e+03	5.930e+10

Comments on Data

Uncertainty in RT C12 value is +/- 1.74, data calculated from Table III.

Reference

USE OF THE IMPULSE METHOD FOR MEASURING THE ELASTIC CONSTANTS OF SOLIDS AT HIGH TEMPERATURES. APPLICATION TO SINGLE-CRYSTAL SILICON.
Ezz-El-Arab, M. A.
ANN. PHYS. (PARIS)
7 (3), 133-58, 1972.

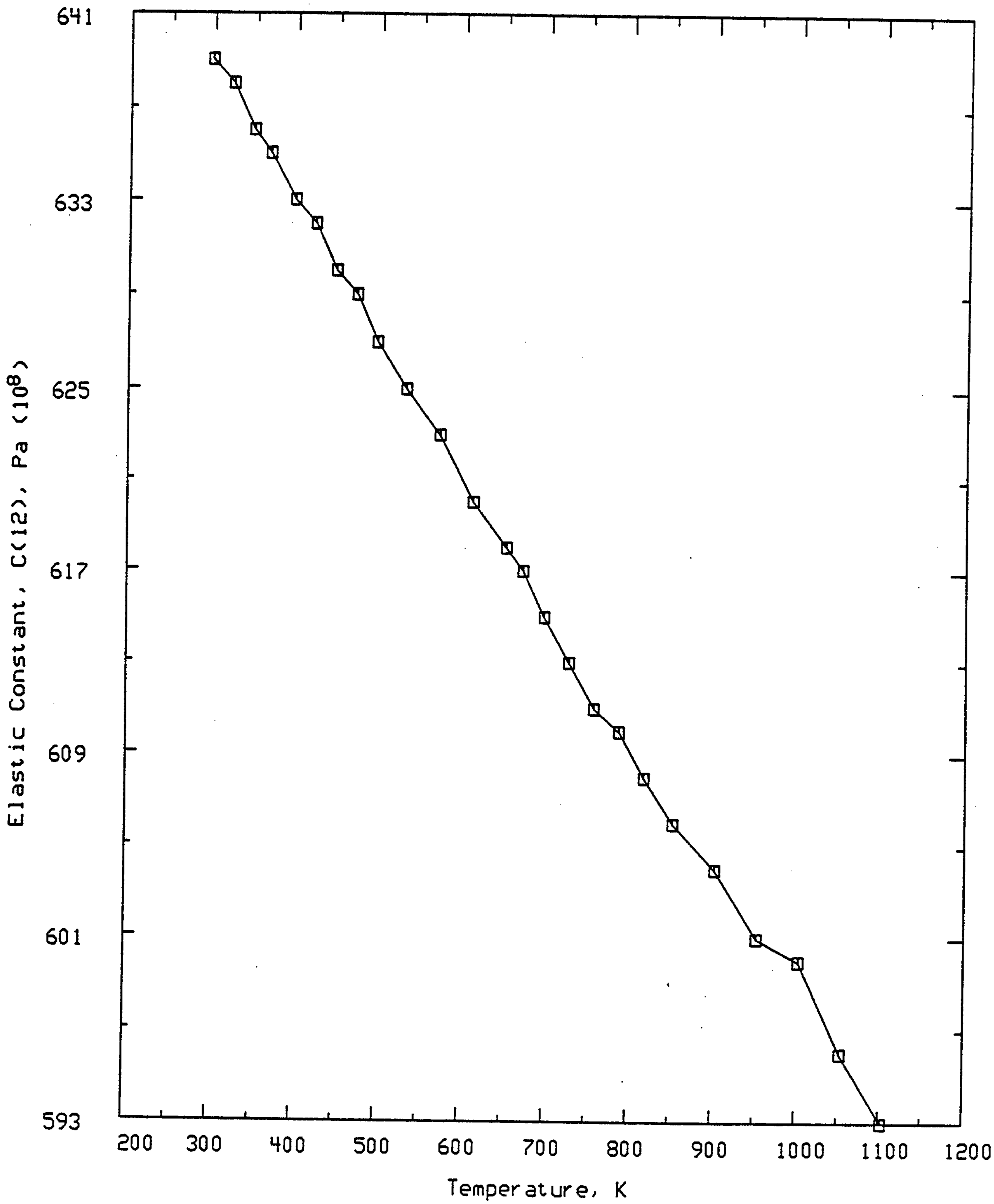

Figure 104 Elastic Constant, C(12) of Silicon, p-type

MATERIAL: Silicon, p-type

PROPERTY: Elastic Constant, C(12)

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PURDUE UNIVERSITY
DATA SET 105

****

Specimen Identification

Dimensions (Geometry) :

Length	20.	mm
Thickness	4.	mm
Width	4.	mm

Additional Properties

Density Initial/Final (295K) :

	2.33	$g\ cm^{-3}$

Additional Properties

Electrical Properties :

Electrical Resistivity	420.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Resonance-Frequency Sound Velocity Technique
Resonance frequencies ranged from 127 to 280 kHz.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :

Pressure	1.e-04	mmHg

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(12)	Pa

Data Points :

X	Y
0.000e+00	6.020e+10
2.930e+02	5.780e+10
3.730e+02	5.780e+10
4.730e+02	5.770e+10
5.730e+02	5.710e+10
6.730e+02	5.620e+10
7.730e+02	5.560e+10
8.730e+02	5.500e+10
9.730e+02	5.480e+10

1.073e+03	5.390e+10
1.173e+03	5.280e+10
1.273e+03	5.150e+10
1.690e+03	4.590e+10

Comments on Data

Data at 0. and 1690. k were extrapolated.
Uncertainty is within +/- 0.4 pct. Data read from table.
The natural frequencies were used to deterimine the Young's moduli and the elasticity moduli as a function of temperature were calculated using published thermal expansion values.

Reference

TEMPERATURE DEPENDENCE OF ELASTIC CONSTANTS OF SILICON.
Burenkov, Yu. A. Nikanorov, S. P.
FIZ. TVERD. TELA (LENINGRAD)
16 (5), 1496-8, 1974.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE, 16 (5), 963-4, 1974)

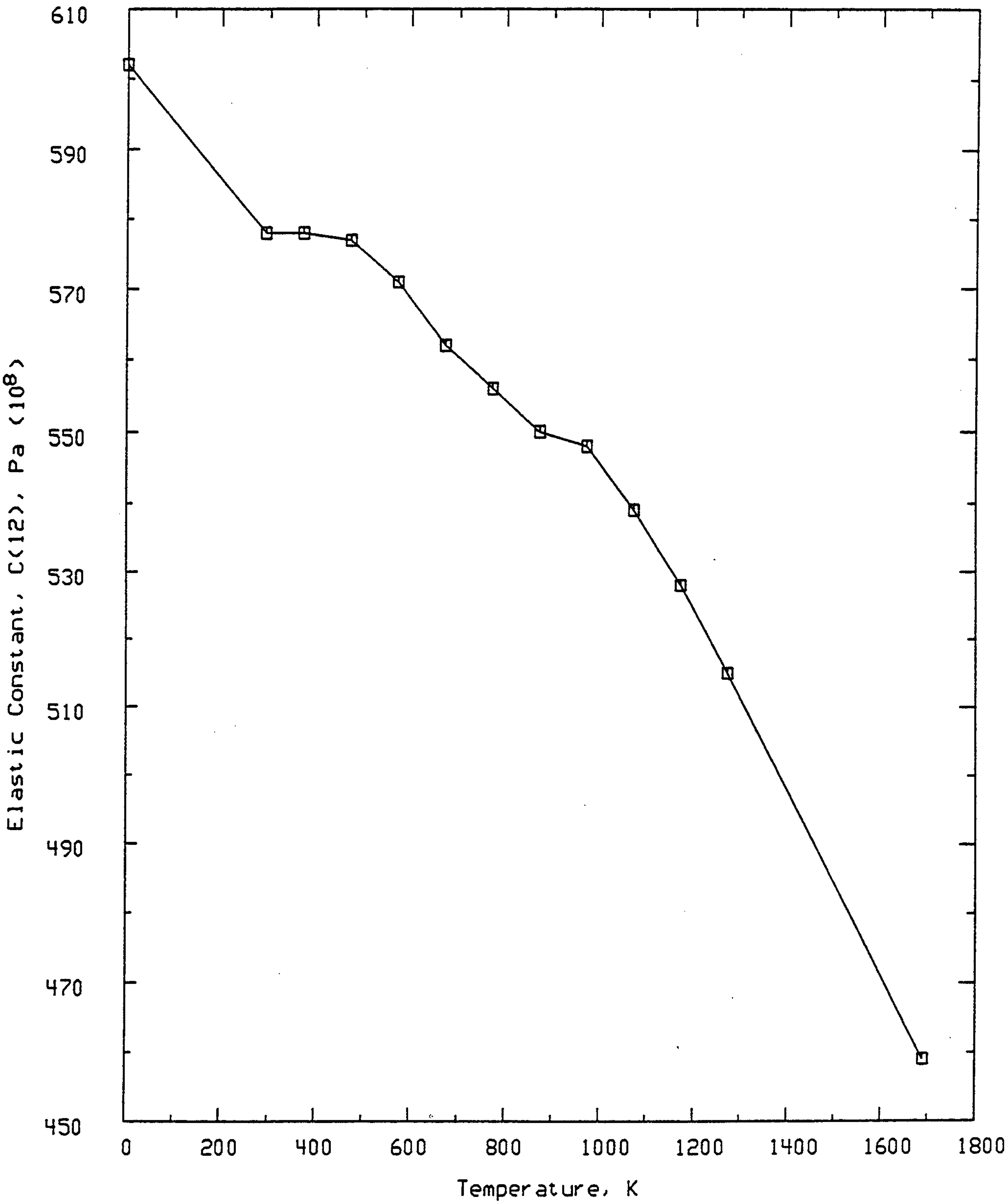

Figure 105 Elastic Constant, C(12) of Silicon, p-type

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(12)

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PURDUE UNIVERSITY
DATA SET 106

****

Specimen Identification

Dimensions (Geometry) :

Length	2.0	cm
Width	1.3	cm

Additional Properties

Density Initial/Final (295K) :

	2.331	g cm^{-3}

Measurement/Evaluation Method

Name/Description :

Single Transducer Sound Velocity Method
Elastic constants calculated from the measured velocities of propagation through the single crystal.

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(12)	Pa

Data Points :

X	Y
7.300e+01	6.498e+10
9.000e+01	6.494e+10
1.000e+02	6.492e+10
1.200e+02	6.485e+10
1.400e+02	6.478e+10
1.600e+02	6.468e+10
1.800e+02	6.458e+10
2.000e+02	6.447e+10
2.200e+02	6.436e+10
2.400e+02	6.424e+10
2.600e+02	6.412e+10
2.800e+02	6.400e+10
3.000e+02	6.388e+10
3.100e+02	6.382e+10

Comments on Data

smoothed data.

Reference

MEASUREMENT OF ELASTIC CONSTANTS AT LOW TEMPERATURES BY MEANS OF ULTRASONIC WAVES - DATA FOR SILICON AND GERMANIUM SINGLE CRYSTALS, AND FOR FUSED SILICA.
McSkimin, H. J.
J. APPL. PHYS.
24 (8), 988-97, 1953.

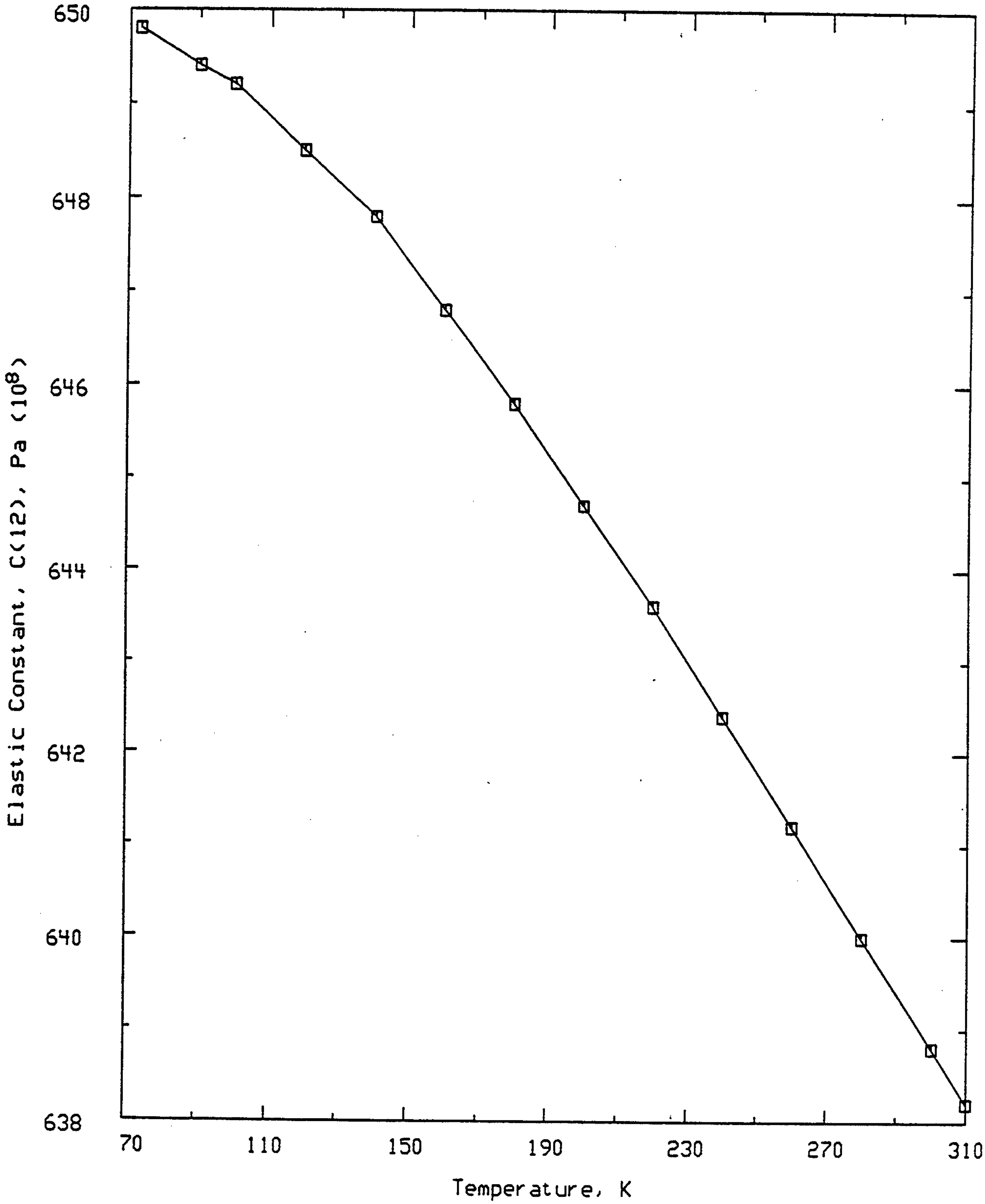

Figure 106 Elastic Constant, C(12) of Silicon

MATERIAL: Silicon: P doped

PROPERTY: Elastic Constant, C(44)

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PURDUE UNIVERSITY
DATA SET 107

****

Composition

2.0e19 cm^{-3} Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :

Specimens prepared from Lopex-grade silicon.

Specimen Identification

Dimensions (Geometry) :

Length	1.5	cm
Width	1.5	cm
Thickness	1.5	cm

Additional Properties

Density Initial/Final (295K) :

	2.3297	$g\ cm^{-3}$

Additional Properties

Carrier/Impurity Conc. :

Dislocation Density	500.	cm^{-2}
Temperature	298.	K

Electrical Properties :

Electrical Resistivity	3.26e-05	Ω m
Temperature	298.	K

Other Properties-Textual :

Carrier density was from Hall effect measurement.

Measurement/Evaluation Method

Name/Description :

Velocity of Sound Method
Sound velocities determined by a pulse-echo technique.
Radio frequency pulses of 12., 36., or 60. MHz were used .

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(44)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	7.999e+10	smoothed data

2.000e+01	7.999e+10
4.000e+01	7.999e+10
6.000e+01	7.997e+10
8.000e+01	7.995e+10
1.000e+02	7.992e+10
1.200e+02	7.988e+10
1.400e+02	7.983e+10
1.600e+02	7.977e+10
1.800e+02	7.971e+10
2.000e+02	7.964e+10
2.200e+02	7.956e+10
2.400e+02	7.948e+10
2.600e+02	7.939e+10
2.800e+02	7.930e+10
3.000e+02	7.920e+10
3.200e+02	7.910e+10

Comments on Data

Data read from figure. Uncertainty is within +/- 1.0 pct.

Reference

ELECTRONIC EFFECTS IN THE ELASTIC CONSTANTS OF n-TYPE SILICON.
Hall, J. J.
PHYS. REV.
161 (3), 756-61, 1967.

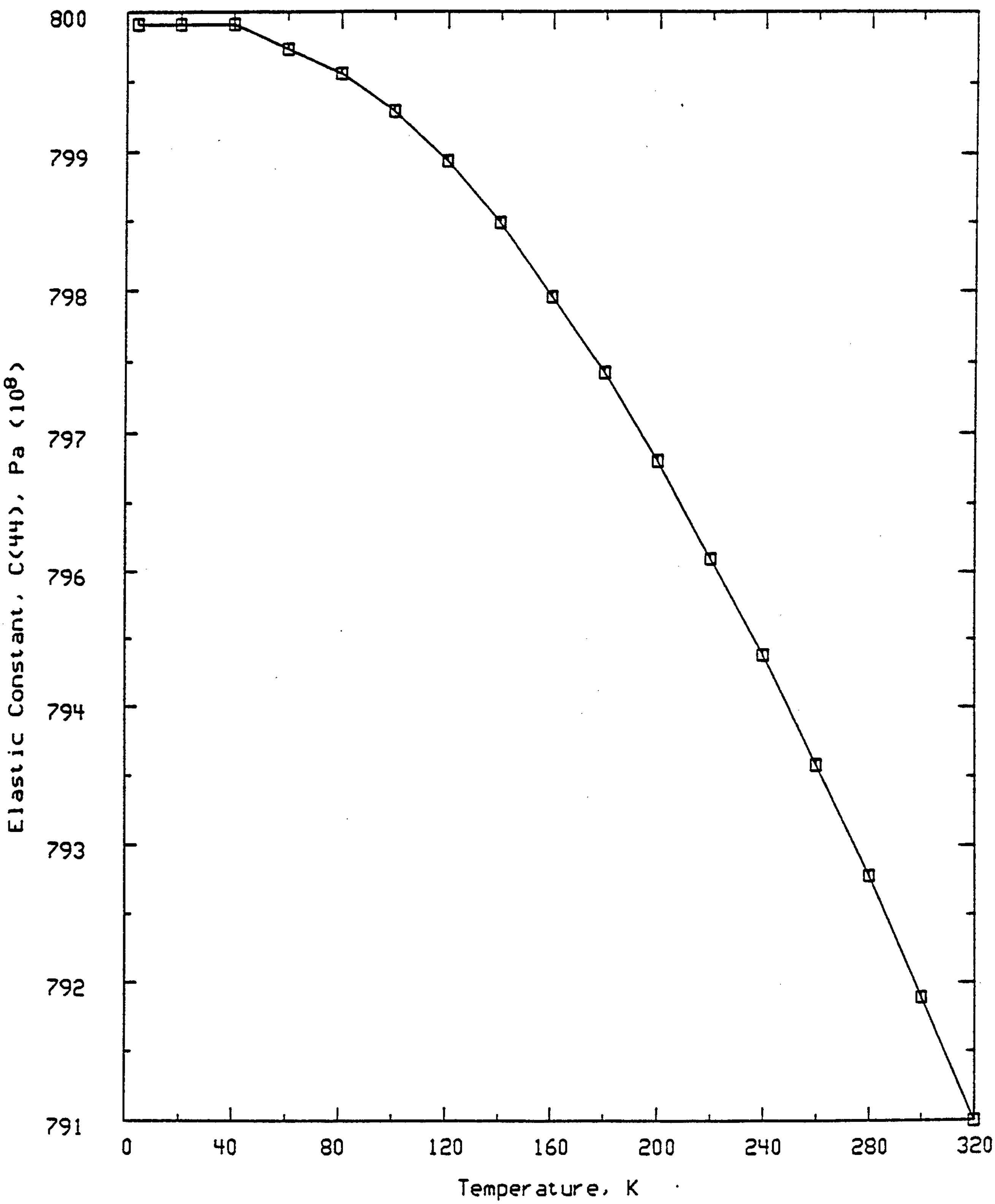

Figure 107 Elastic Constant, C(44) of Silicon: P doped

MATERIAL: Silicon, n-type

PROPERTY: Elastic Constant, C(44)

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PURDUE UNIVERSITY
DATA SET 108

****

Material Preparation

Crystal Growing Method :

Specimens prepared from Lopex-grade silicon.

Specimen Identification

Dimensions (Geometry) :

Length	1.5	cm
Width	1.5	cm
Thickness	1.5	cm

Additional Properties

Density Initial/Final (295K) :

	2.3290	g cm^{-3}

Additional Properties

Carrier/Impurity Conc. :

Dislocation Density	500.	cm^{-2}
Temperature	298.	K

Electrical Properties :

Electrical Resistivity	150.	10^{-3} Ω cm
Temperature	298.	K

Other Properties-Textual :

Carrier density was from Hall effect measurement.

Measurement/Evaluation Method

Name/Description :

Velocity of Sound Method

Sound velocities determined by a pulse-echo technique.

Radio frequency pulses of 12., 36., or 60. MHz were used .

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(44)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	8.016e+10	smoothed data
2.000e+01	8.019e+10	
4.000e+01	8.022e+10	
6.000e+01	8.022e+10	

8.000e+01	8.022e+10
1.000e+02	8.020e+10
1.200e+02	8.017e+10
1.400e+02	8.012e+10
1.600e+02	8.007e+10
1.800e+02	8.001e+10
2.000e+02	7.994e+10
2.200e+02	7.986e+10
2.400e+02	7.978e+10
2.600e+02	7.970e+10
2.800e+02	7.961e+10
3.000e+02	7.952e+10
3.200e+02	7.943e+10

Comments on Data

Data read from figure. Uncertainty is within +/- 1.0 pct.

Reference

ELECTRONIC EFFECTS IN THE ELASTIC CONSTANTS OF n-TYPE SILICON.
Hall, J. J.
PHYS. REV.
161 (3), 756-61, 1967.

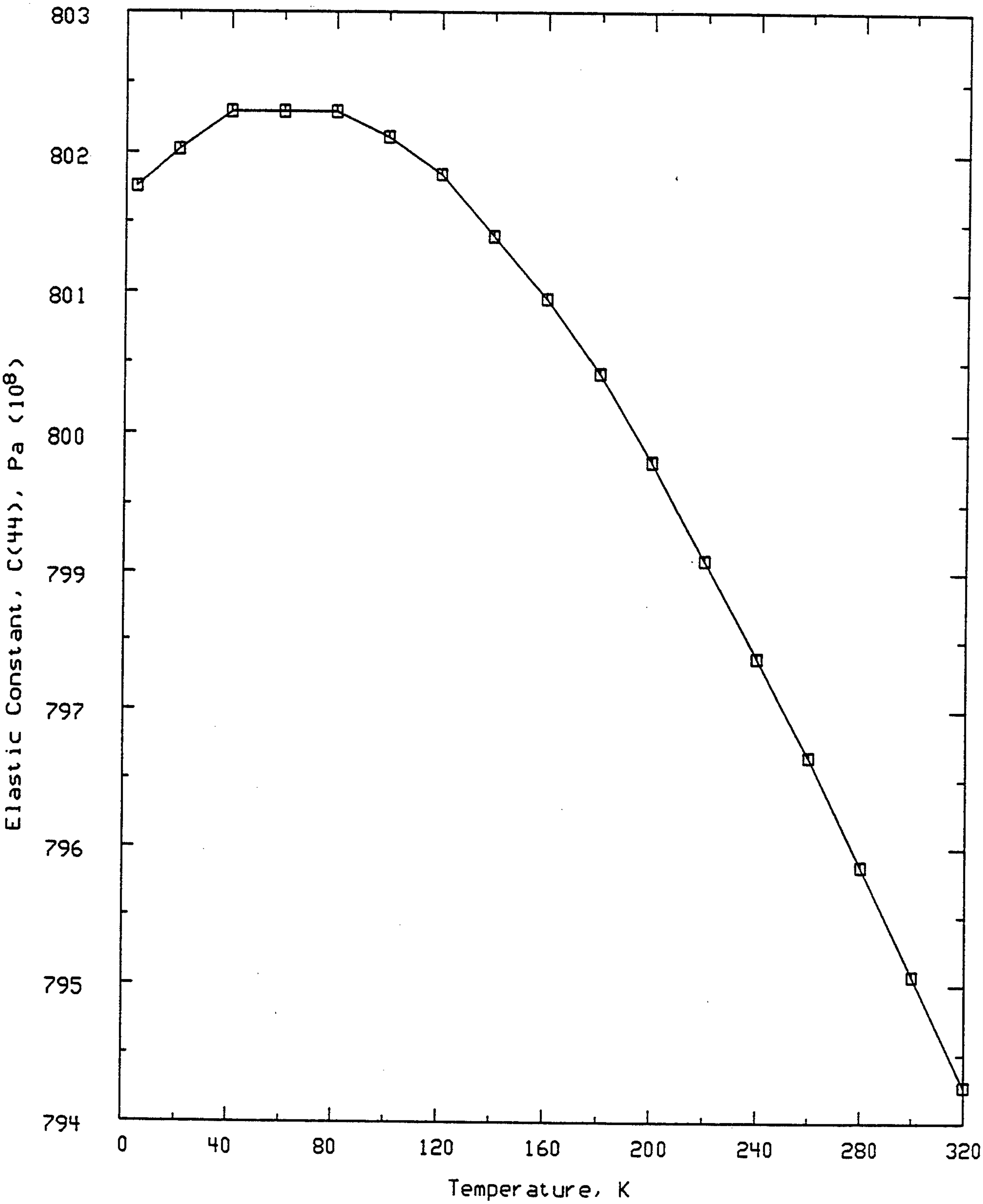

Figure 108 Elastic Constant, C(44) of Silicon, n-type

MATERIAL: Silicon, p-type

PROPERTY: Elastic Constant, C(44)

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PURDUE UNIVERSITY
DATA SET 109

****

Composition

99.993	weight percent	Silicon
10	ppm atomic	Aluminum
<2	ppm atomic	Boron
<3	ppm atomic	Chromium
20	ppm atomic	Copper
25	ppm atomic	Iron
<3	ppm atomic	Magnesium
3	ppm atomic	Manganese
<3	ppm atomic	Nickel
<0.5	ppm atomic	Silver

Specimen Identification

Dimensions (Geometry) :

Length	25.0	mm
Diameter	25.0	mm

Additional Properties

Density Initial/Final (295K) :

	2.329	g cm^{-3}

Additional Properties

Electrical Properties :

Electrical Resistivity	0.22	Ω cm
Temperature	298.	K
Hole Concentration	4.8e16	cm^{-3}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Pulse-Echo Sound Velocity Technique
Elastic constants calculated from the measured velocities through the single crystal.

Parameters-Textual :

Frequency was 30 MHz with 1.5 kHz band

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(44)	Pa

Data Points :

X	Y
2.980e+02	7.900e+10
3.230e+02	7.890e+10
3.480e+02	7.880e+10
3.680e+02	7.870e+10
3.980e+02	7.850e+10
4.230e+02	7.840e+10
4.480e+02	7.830e+10
4.730e+02	7.810e+10
4.980e+02	7.800e+10
5.330e+02	7.780e+10
5.730e+02	7.750e+10
6.130e+02	7.730e+10
6.530e+02	7.710e+10
6.730e+02	7.690e+10
6.980e+02	7.680e+10
7.280e+02	7.660e+10
7.580e+02	7.640e+10
7.880e+02	7.620e+10
8.180e+02	7.600e+10
8.530e+02	7.580e+10
9.030e+02	7.550e+10
9.530e+02	7.510e+10
1.003e+03	7.480e+10
1.053e+03	7.440e+10
1.103e+03	7.410e+10

Comments on Data

Uncertainty in RT C44 value is +/- 0.32, data calculated from Table III.

Reference

USE OF THE IMPULSE METHOD FOR MEASURING THE ELASTIC CONSTANTS OF SOLIDS AT HIGH TEMPERATURES. APPLICATION TO SINGLE-CRYSTAL SILICON.
Ezz-El-Arab, M. A.
ANN. PHYS. (PARIS)
7 (3), 133-58, 1972.

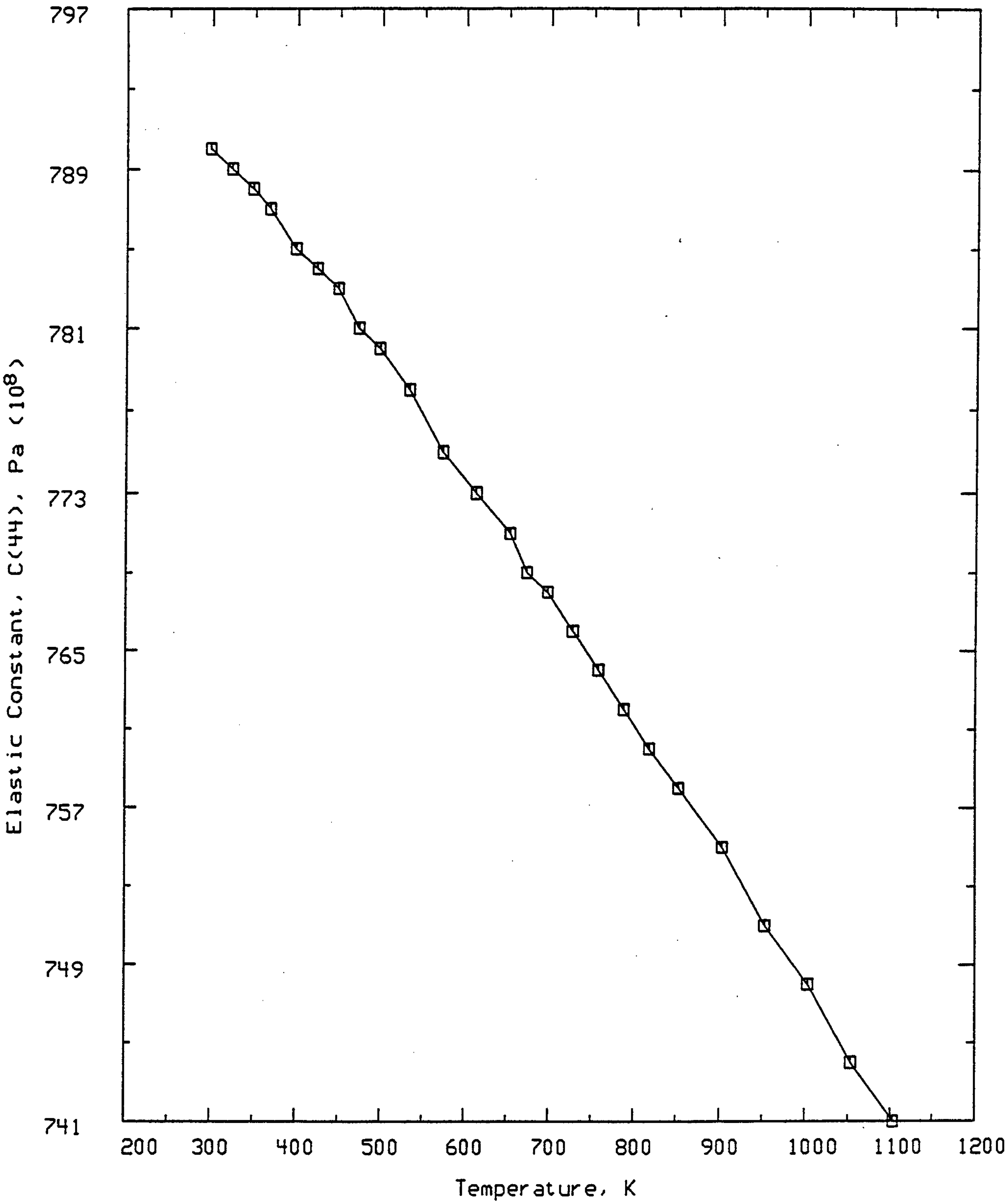

Figure 109 Elastic Constant, C(44) of Silicon, p-type

MATERIAL: Silicon, p-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Elastic Constant, C(44)	DATA SET 110

****

Specimen Identification

Dimensions (Geometry) :		
Length	20.	mm
Thickness	4.	mm
Width	4.	mm

Additional Properties

Density Initial/Final (295K) :		
	2.33	g cm^{-3}

Additional Properties

Electrical Properties :		
Electrical Resistivity	420.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Resonance-Frequency Sound Velocity Technique
Resonance frequencies ranged from 135 to 280 kHz.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :		
Pressure	1.e-04	mmHg

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(44)	Pa

Data Points :

X	Y
0.000e+00	8.200e+10
2.930e+02	8.000e+10
3.730e+02	7.950e+10
4.730e+02	7.900e+10
5.730e+02	7.840e+10
6.730e+02	7.780e+10
7.730e+02	7.720e+10
8.730e+02	7.660e+10
9.730e+02	7.590e+10

1.073e+03	7.520e+10
1.173e+03	7.450e+10
1.273e+03	7.370e+10
1.690e+03	7.040e+10

Comments on Data

Data at 0. and 1690. k were extrapolated.
Uncertainty is within +/- 0.4 pct. Data read from table.
The natural frequencies were used to deterimine the Young's moduli and the elasticity moduli as a function of temperature were calculated using published thermal expansion values.

Reference

TEMPERATURE DEPENDENCE OF ELASTIC CONSTANTS OF SILICON.
Burenkov, Yu. A. Nikanorov, S. P.
FIZ. TVERD. TELA (LENINGRAD)
16 (5), 1496-8, 1974.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE, 16 (5), 963-4, 1974)

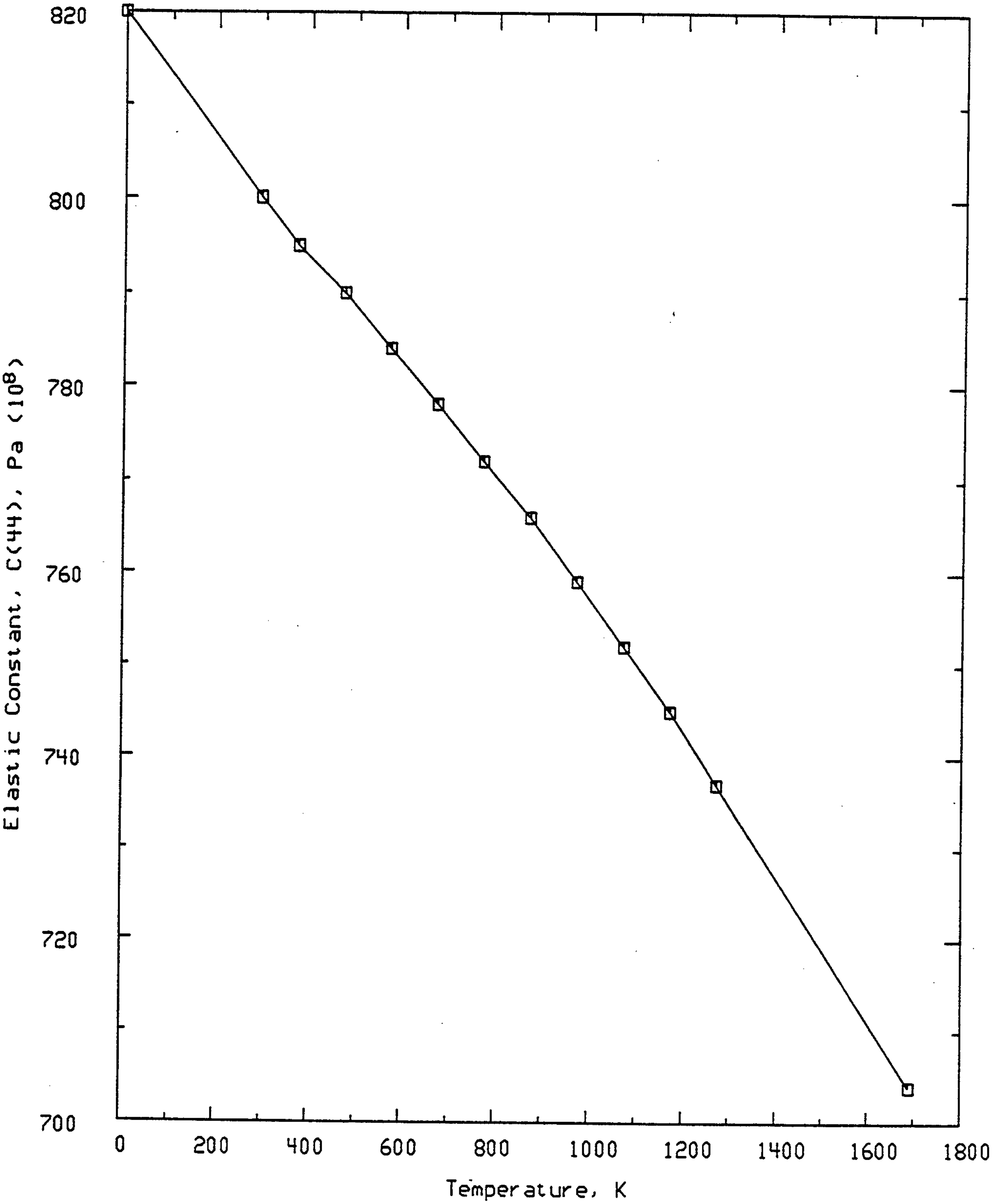

Figure 110 Elastic Constant, C(44) of Silicon, p-type

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(44)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 111

****

Specimen Identification

Dimensions (Geometry) :

Length	2.0	cm
Width	1.3	cm

Additional Properties

Density Initial/Final (295K) :

2.331 g cm^{-3}

Measurement/Evaluation Method

Name/Description :

Single Transducer Sound Velocity Method
Elastic constants calculated from the measured velocities of propagation through the single crystal.

Measured/Evaluated Properties

X : Temperature — K
Y : Elastic Constant, C(44) — Pa

Data Points :

X	Y
7.300e+01	8.007e+10
9.000e+01	8.006e+10
1.000e+02	8.006e+10
1.200e+02	8.004e+10
1.400e+02	8.001e+10
1.600e+02	7.997e+10
1.800e+02	7.992e+10
2.000e+02	7.987e+10
2.200e+02	7.981e+10
2.400e+02	7.975e+10
2.600e+02	7.968e+10
2.800e+02	7.961e+10
3.000e+02	7.954e+10
3.100e+02	7.951e+10

Comments on Data

smoothed data.

Reference

MEASUREMENT OF ELASTIC CONSTANTS AT LOW TEMPERATURES BY MEANS OF ULTRASONIC WAVES - DATA FOR SILICON AND GERMANIUM SINGLE CRYSTALS, AND FOR FUSED SILICA.
McSkimin, H. J.
J. APPL. PHYS.
24 (8), 988-97, 1953.

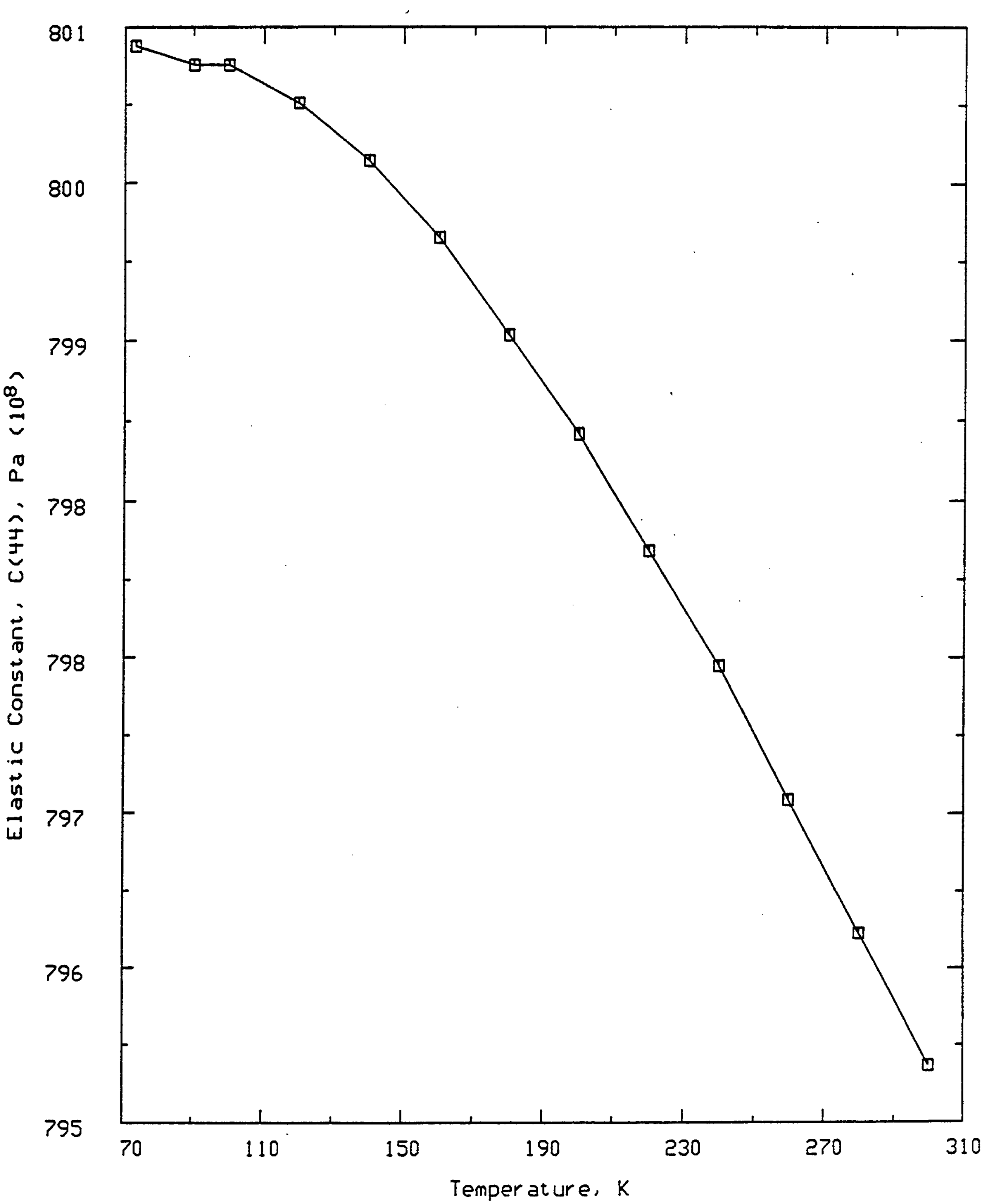

Figure 111 Elastic Constant, C(44) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(111)

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PURDUE UNIVERSITY
DATA SET 112

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.5214	cm

Additional Identifiers :

Length is average of 2.5171, 2.5222, and 2.5248 cm along [100], [110], and [111] orientations, respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique

Parameters-Textual :

hird and or elastic constants by harmonic generation.
Excitation of finite amplitude longitudinal ultrasonic wave.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine nonlinearity parameters.

Parameters-Codified :

Frequency : 30 MHz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(111)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	-8.800e+11	St. dev.=+/-16 GPa
7.700e+01	-8.490e+11	St. dev.=+/-14 GPa
2.980e+02	-8.340e+11	St. dev.=+/-11 GPa

Comments on Data

Data taken from table.
Agreement with theory is good.

Reference

TEMPERATURE VARIATION OF SOME COMBINATIONS OF THIRD-ORDER ELASTIC CONSTANTS OF SILICON BETWEEN 300 AND 3 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
52 (5), 3383-7, 1981.

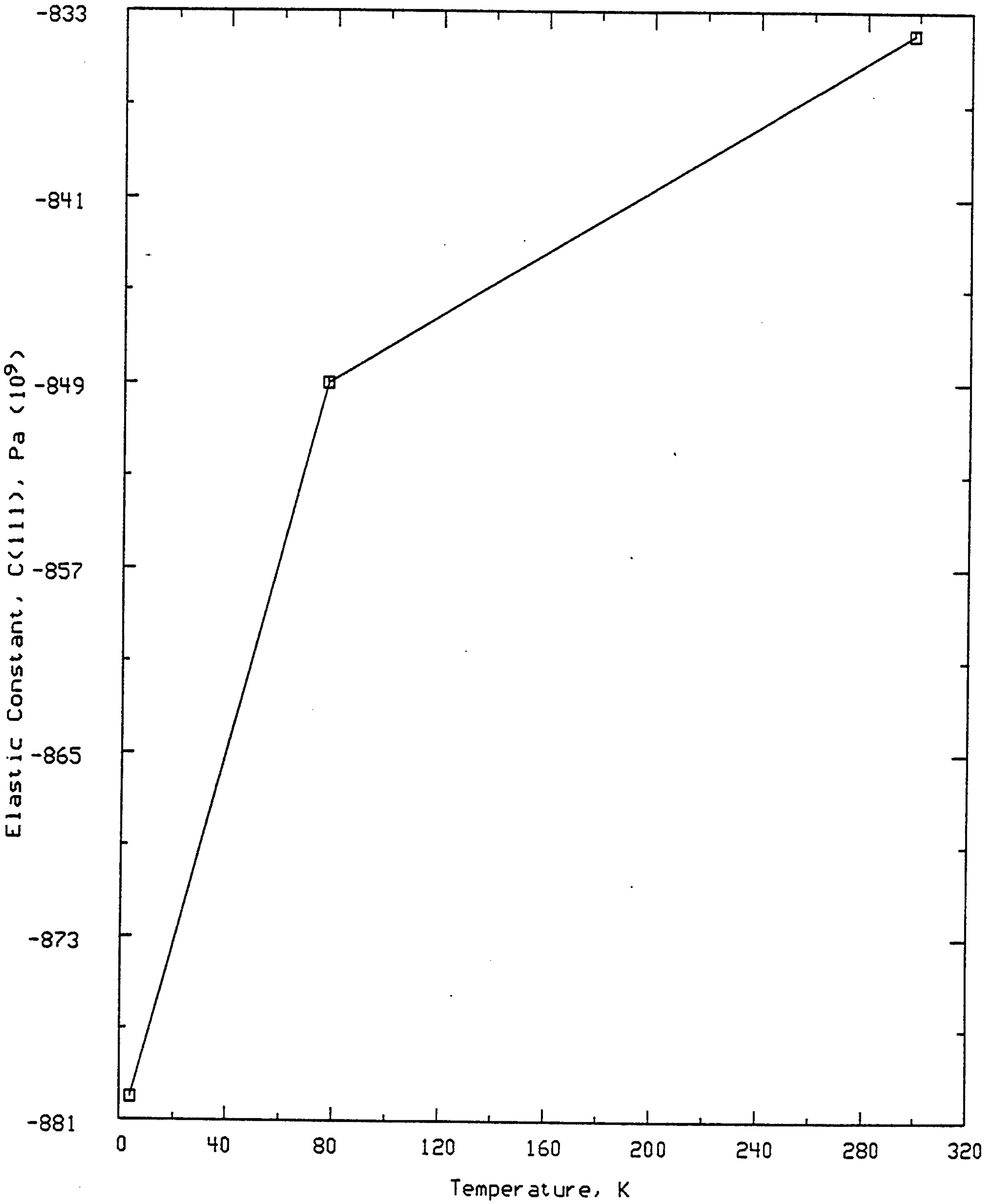

Figure 112 Elastic Constant, C(111) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(111)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 113

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends are lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.539	cm

Additional Identifiers :

Length is average of 2.571, 2.522, and 2.5248 cm in [100] [110], and [111] orientations respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique

Parameters-Textual :

Excitation of a finite amplitude longitudinal ultrasonic wave which propegates along the principal crystallographic direction. Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine the nonlinearity parameter which contain three linear combinations of 3rd order elastic constants.

Parameters-Codified :

Frequency : 30 M Hz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(111)	Pa

Data Points :

X	Y
4.000e+00	-8.750e+11
9.000e+00	-8.810e+11
2.400e+01	-8.680e+11
4.200e+01	-8.810e+11
6.000e+01	-8.550e+11
7.700e+01	-8.550e+11

9.900e+01	-8.420e+11
1.180e+02	-8.550e+11
1.310e+02	-8.480e+11
1.480e+02	-8.480e+11
1.680e+02	-8.480e+11
2.000e+02	-8.470e+11
2.250e+02	-8.530e+11
2.420e+02	-8.470e+11
2.610e+02	-8.460e+11
2.720e+02	-8.460e+11
2.990e+02	-8.330e+11

Comments on Data

Data read from figure 3.

Reference

THIRD-ORDER ELASTIC CONSTANTS AND GRUENEISEN PARAMETERS OF SILICON AND GERMANIUM BETWEEN 3 AND 300 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
54 (2), 752-7, 1983.

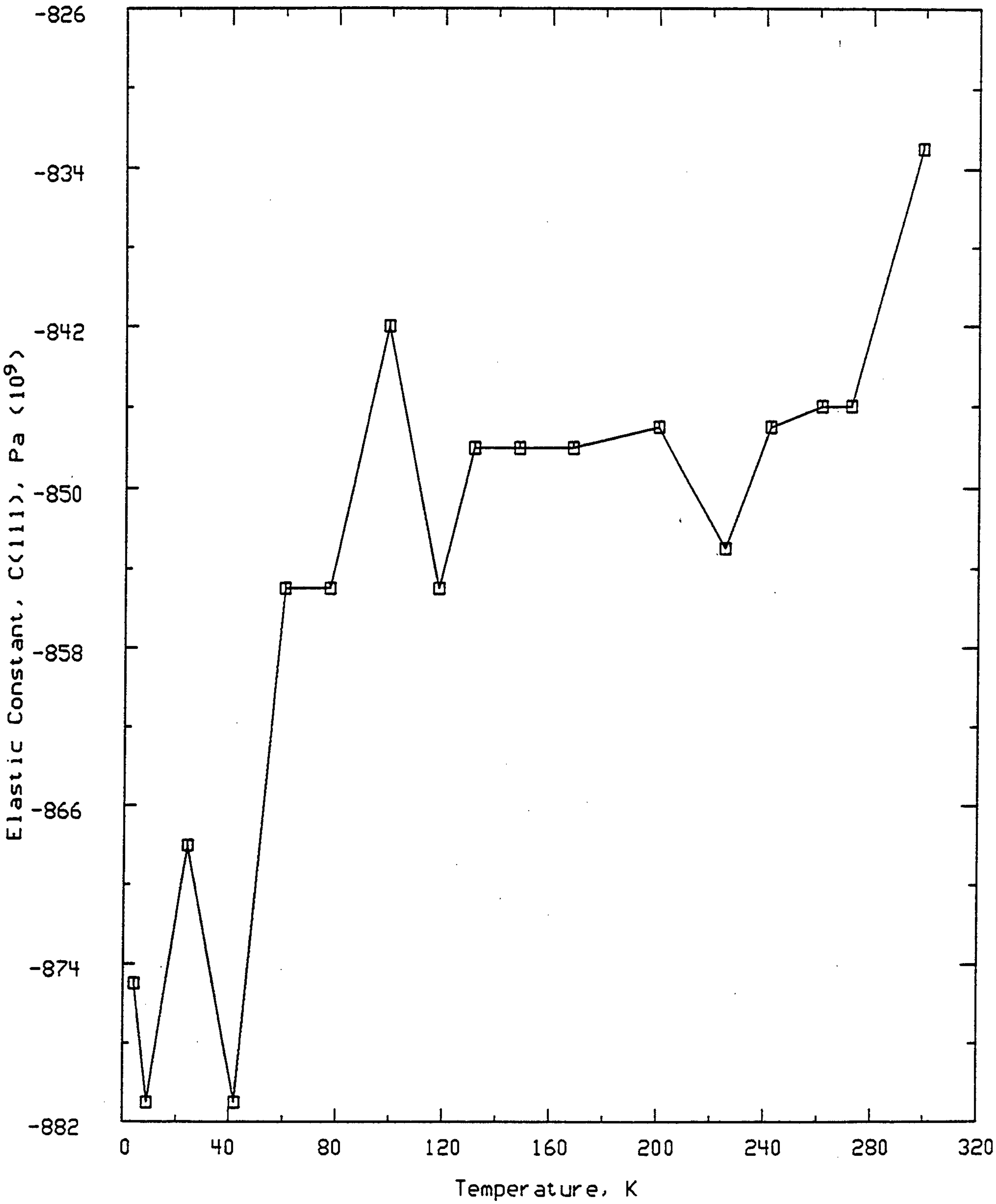

Figure 113 Elastic Constant, C(111) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(112)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 114

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.5214	cm

Additional Identifiers :

Length is average of 2.5171, 2.5222, and 2.5248 cm along [100], [110], and [111] orientations, respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of finite amplitude longitudinal ultrasonic wave.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine nonlinearity parameters.

Parameters-Codified :

Frequency : 30 MHz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(112)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	-5.150e+11	St. dev.=+/-26 GPa
7.700e+01	-5.240e+11	St.dev.=+/-31 GPa
2.980e+02	-5.310e+11	St. Dev.=+/-32 GPa

Comments on Data

Data taken from table.
Agreement with theory is good.

Reference

TEMPERATURE VARIATION OF SOME COMBINATIONS OF

THIRD-ORDER ELASTIC CONSTANTS OF SILICON BETWEEN 300 AND 3 DEGREE K.

Philip, J. Breazeale, M. A.

J. APPL. PHYS.

52 (5), 3383-7, 1981.

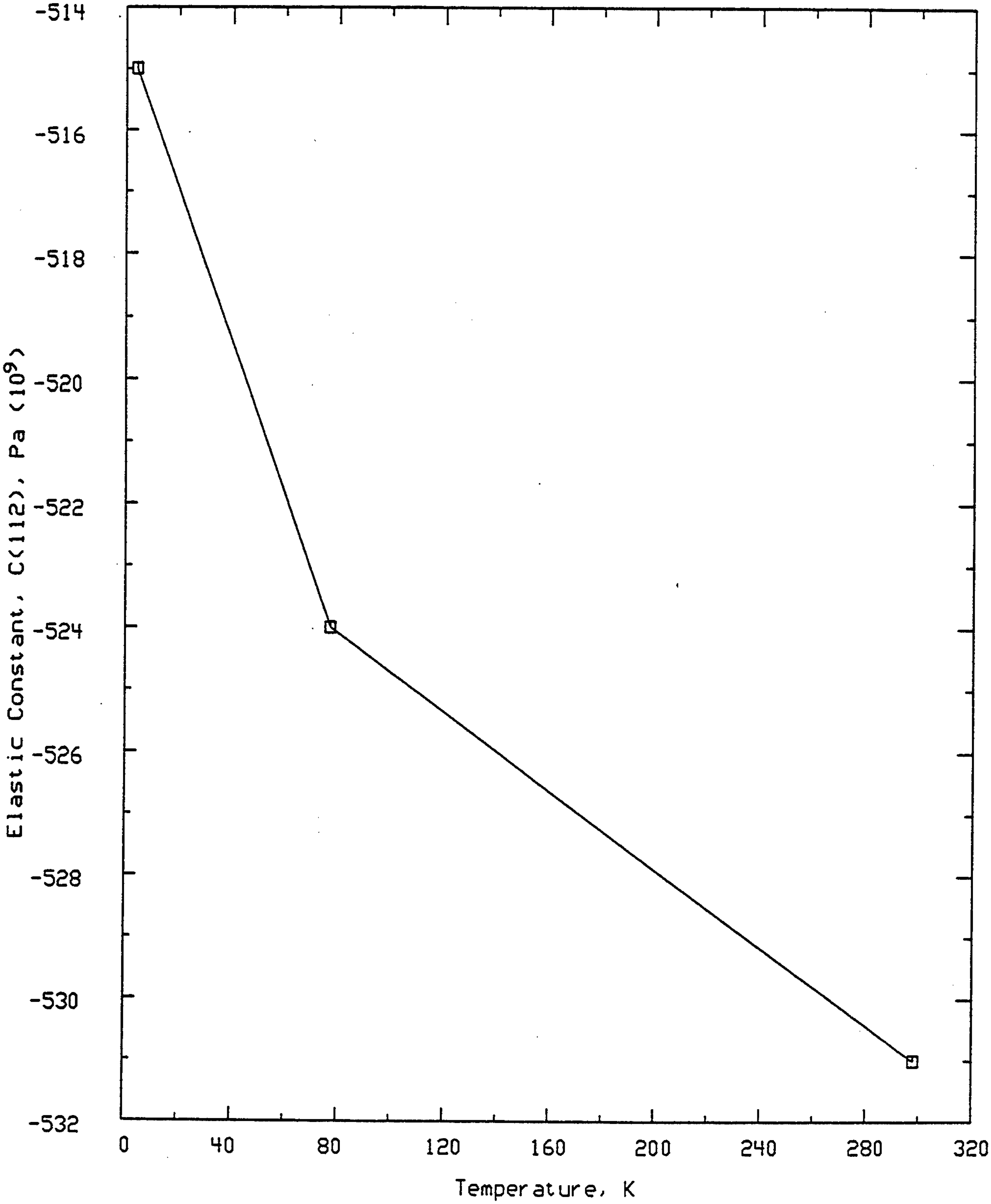

Figure 114 Elastic Constant, C(112) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(112)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 115

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends are lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.539	cm

Additional Identifiers :

Length is average of 2.571, 2.522, and 2.5248 cm in [100] [110], and [111] orientations respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique

Excitation of a finite amplitude longitudinal ultrasonic wave which propagates along the principal crystallographic direction. Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine the nonlinearity parameter which contain three linear combinations of 3rd order elastic constants.

Parameters-Codified :

Frequency : 30 M Hz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(112)	Pa

Data Points :

X	Y
4.000e+00	-4.310e+10
1.000e+01	-4.620e+10
1.500e+01	-4.620e+10
2.400e+01	-4.680e+10
4.500e+01	-4.810e+10
6.100e+01	-4.990e+10
7.700e+01	-5.050e+10

1.010e+02	-5.050e+10
1.170e+02	-5.050e+10
1.310e+02	-4.980e+10
1.490e+02	-5.100e+10
1.690e+02	-5.100e+10
1.990e+02	-5.030e+10
2.240e+02	-5.030e+10
2.430e+02	-5.090e+10
2.630e+02	-5.090e+10
2.730e+02	-5.090e+10
2.980e+02	-5.020e+10

Comments on Data

Data read from figure 3.

Reference

THIRD-ORDER ELASTIC CONSTANTS AND GRUENEISEN PARAMETERS OF SILICON AND GERMANIUM BETWEEN 3 AND 300 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
54 (2), 752-7, 1983.

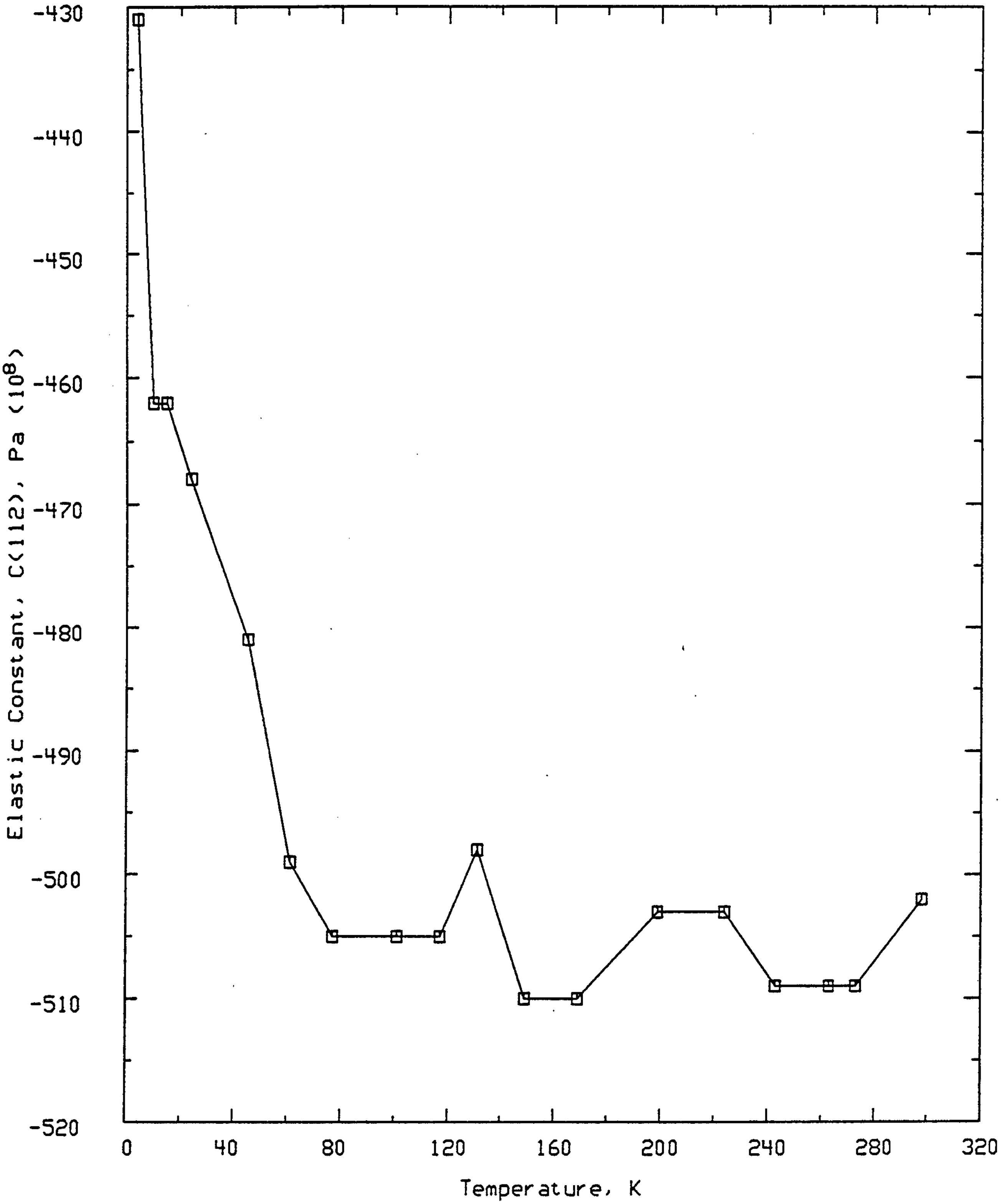

Figure 115 Elastic Constant, C(112) of Silicon

MATERIAL: Silicon

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 116

PROPERTY: Elastic Constant, C(123)

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.5214	cm

Additional Identifiers :

Length is average of 2.5171, 2.5222, and 2.5248 cm along [100], [110], and [111] orientations, respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of finite amplitude longitudinal ultrasonic wave.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine nonlinearity parameters.

Parameters-Codified :

Frequency : 30 MHz

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(123)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	2.700e+10	St. dev.=+/-24 GPa
7.700e+01	-8.000e+09	St. dev.=+/-20 GPa
2.980e+02	-2.000e+09	St. dev.=+/-18 GPa

Comments on Data

Data taken from table.
Agreement with theory is good.

Reference

TEMPERATURE VARIATION OF SOME COMBINATIONS OF

THIRD-ORDER ELASTIC CONSTANTS OF SILICON BETWEEN 300 AND 3 DEGREE K.

Philip, J. Breazeale, M. A.

J. APPL. PHYS.
52 (5), 3383-7, 1981.

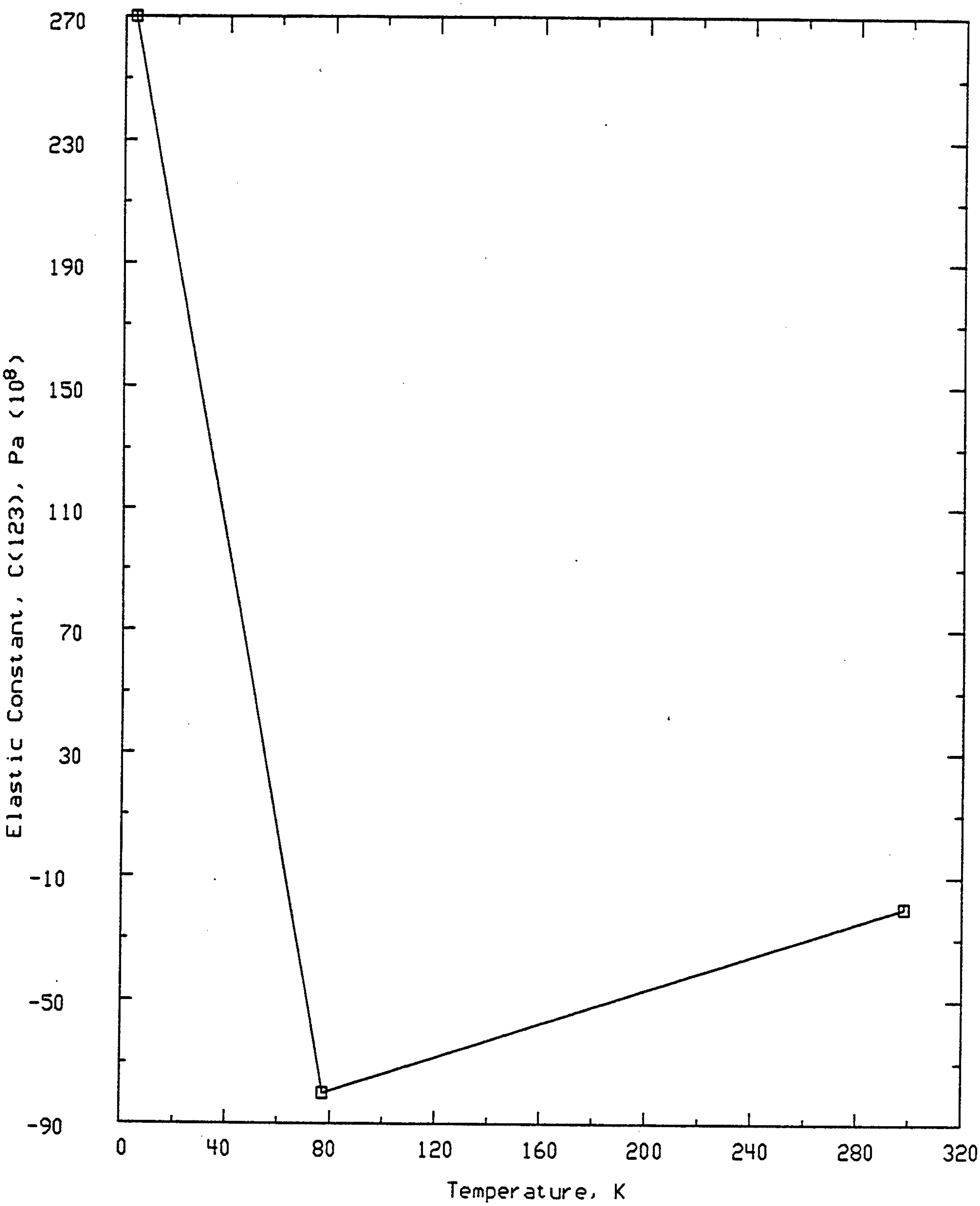

Figure 116 Elastic Constant, C(123) of Silicon

MATERIAL: Silicon | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Elastic Constant, C(123) | DATA SET 117

****

Descriptors-Textual :
After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :
Sample ends are lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.539	cm

Additional Identifiers :
Length is average of 2.571, 2.522, and 2.5248 cm in [100] [110], and [111] orientations respectively.

Measurement/Evaluation Method

Name/Description :
Ultrasonic Harmonic Generation Technique

Parameters-Textual :
Excitation of a finite amplitude longitudinal ultrasonic wave which propegates along the principal crystallographic direction. Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine the nonlinearity parameter which contain three linear combinations of 3rd order elastic constants.

Parameters-Codified :
Frequency : 30 M Hz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(123)	Pa

Data Points :

X	Y
4.000e+00	5.810e+10
7.000e+00	4.500e+10
1.500e+01	-1.530e+10
2.200e+01	-3.490e+10
3.000e+01	-5.320e+10
3.900e+01	-8.470e+10

4.700e+01	-9.910e+10
5.800e+01	-1.265e+11
6.800e+01	-1.567e+11
8.100e+01	-1.593e+11
1.220e+02	-1.658e+11
1.350e+02	-1.697e+11
1.500e+02	-1.631e+11
1.710e+02	-1.762e+11
2.000e+02	-1.853e+11
2.240e+02	-1.839e+11
2.430e+02	-1.891e+11
2.610e+02	-1.891e+11
2.730e+02	-1.917e+11
3.000e+02	-1.891e+11

Comments on Data

Data read from figure.
Shows maximum sensitivity to temperature.

Reference

THIRD-ORDER ELASTIC CONSTANTS AND GRUENEISEN PARAMETERS OF SILICON AND GERMANIUM BETWEEN 3 AND 300 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
54 (2), 752-7, 1983.

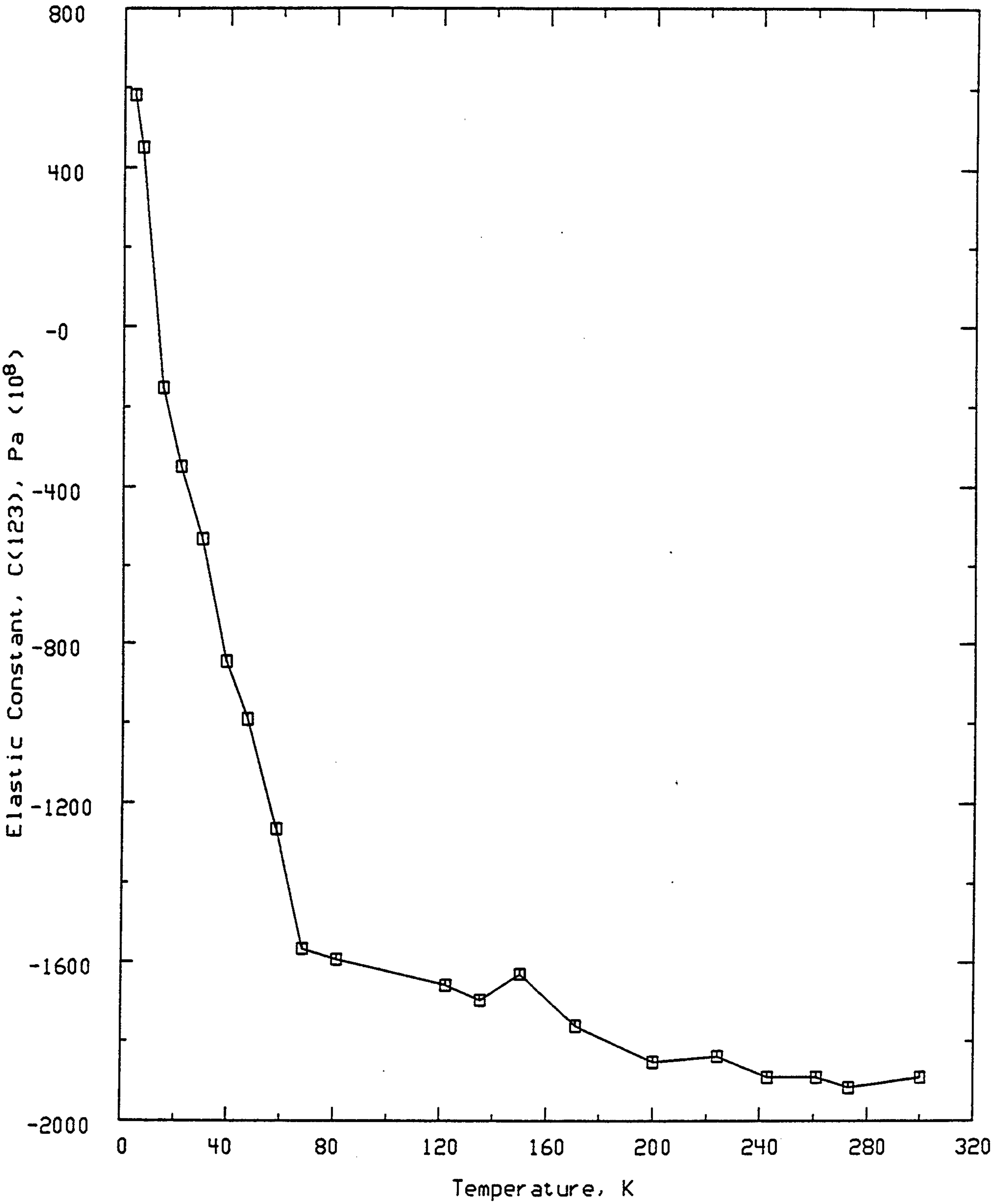

Figure 117 Elastic Constant, C(123) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(144)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 118

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.5214	cm

Additional Identifiers :

Length is average of 2.5171, 2.5222, and 2.5248 cm along [100], [110], and [111] orientations, respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of finite amplitude longitudinal ultrasonic wave.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine nonlinearity parameters.

Parameters-Codified :

Frequency : 30 MHz

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(144)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	7.400e+10	St. dev.=+/-8 GPa
7.700e+01	-4.900e+10	St. dev.=+/-10 GPa
2.980e+02	-9.500e+10	St. dev.=+/-24 GPa

Comments on Data

Data taken from table.
Agreement with theory is good.

Reference

TEMPERATURE VARIATION OF SOME COMBINATIONS OF

THIRD-ORDER ELASTIC CONSTANTS OF SILICON BETWEEN 300 AND 3 DEGREE K.
Philip, J.   Breazeale, M. A.
J. APPL. PHYS.
52 (5), 3383-7, 1981.

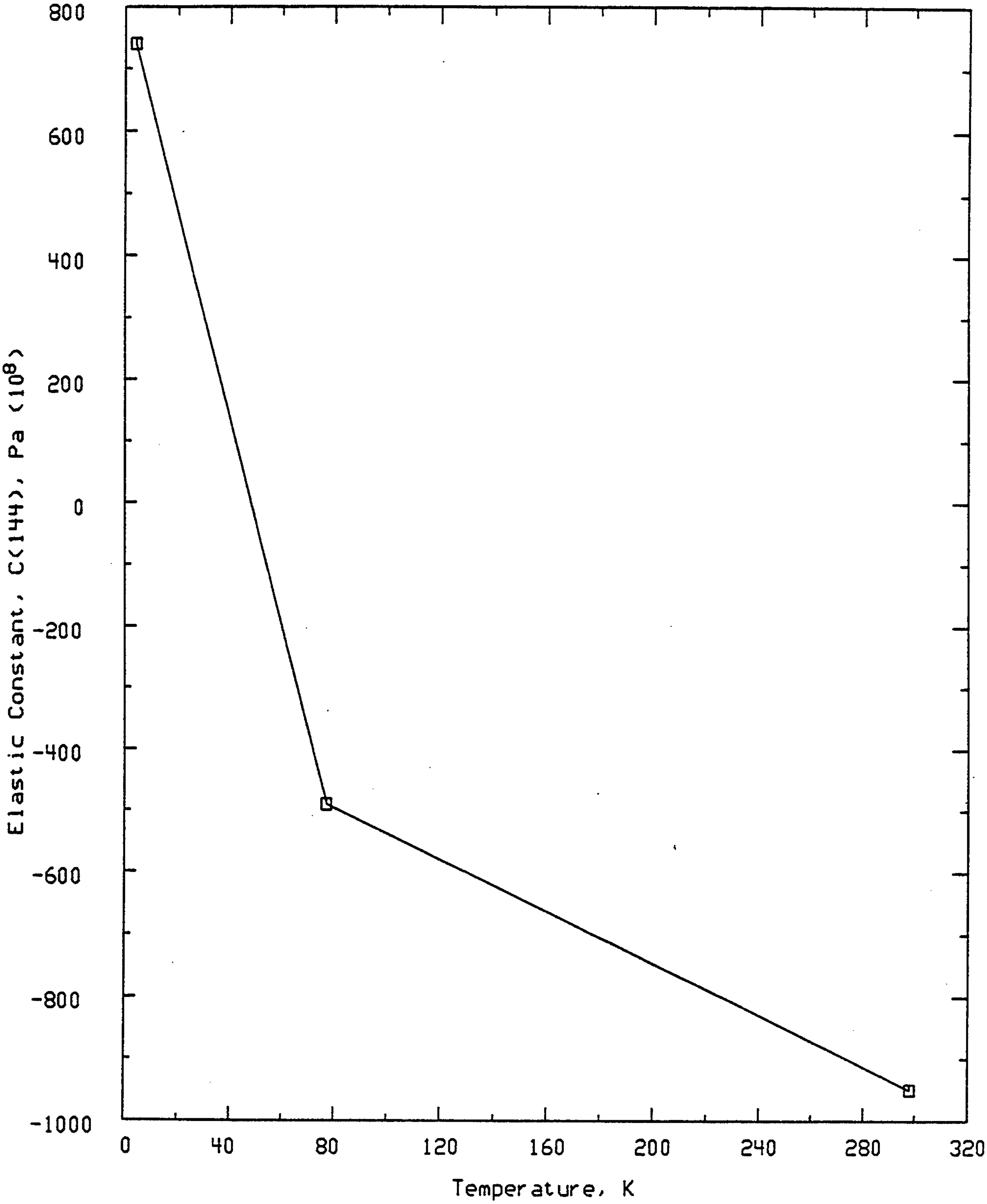

Figure 118 Elastic Constant, C(144) of Silicon

MATERIAL: Silicon

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 119

PROPERTY: Elastic Constant, C(144)

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends are lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.539	cm

Additional Identifiers :

Length is average of 2.571, 2.522, and 2.5248 cm in [100] [110], and [111] orientations respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of a finite amplitude longitudinal ultrasonic wave which propegates along the principal crystallographic direction.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine the nonlinearity parameter which contain three linear combinations of 3rd order elastic constants.

Parameters-Codified :

Frequency : 30 M Hz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(144)	Pa

Data Points :

X	Y
4.000e+00	5.260e+10
9.000e+00	3.180e+10
1.600e+01	2.830e+10
2.500e+01	2.130e+10
3.500e+01	9.700e+09
4.400e+01	2.700e+09
5.100e+01	-3.100e+09

6.200e+01	-6.600e+09
7.700e+01	-5.500e+09
1.000e+02	-1.020e+10
1.170e+02	-1.030e+10
1.310e+02	-1.040e+10
1.470e+02	-1.160e+10
1.680e+02	-1.400e+10
1.980e+02	-1.640e+10
2.240e+02	-1.900e+10
2.420e+02	-2.010e+10
2.630e+02	-2.020e+10
2.740e+02	-2.140e+10
3.010e+02	-2.270e+10

Comments on Data

Data read from figure 4.
Shows maximum sensitivity to temperature.

Reference

THIRD-ORDER ELASTIC CONSTANTS AND GRUENEISEN PARAMETERS OF SILICON AND GERMANIUM BETWEEN 3 AND 300 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
54 (2), 752-7, 1983.

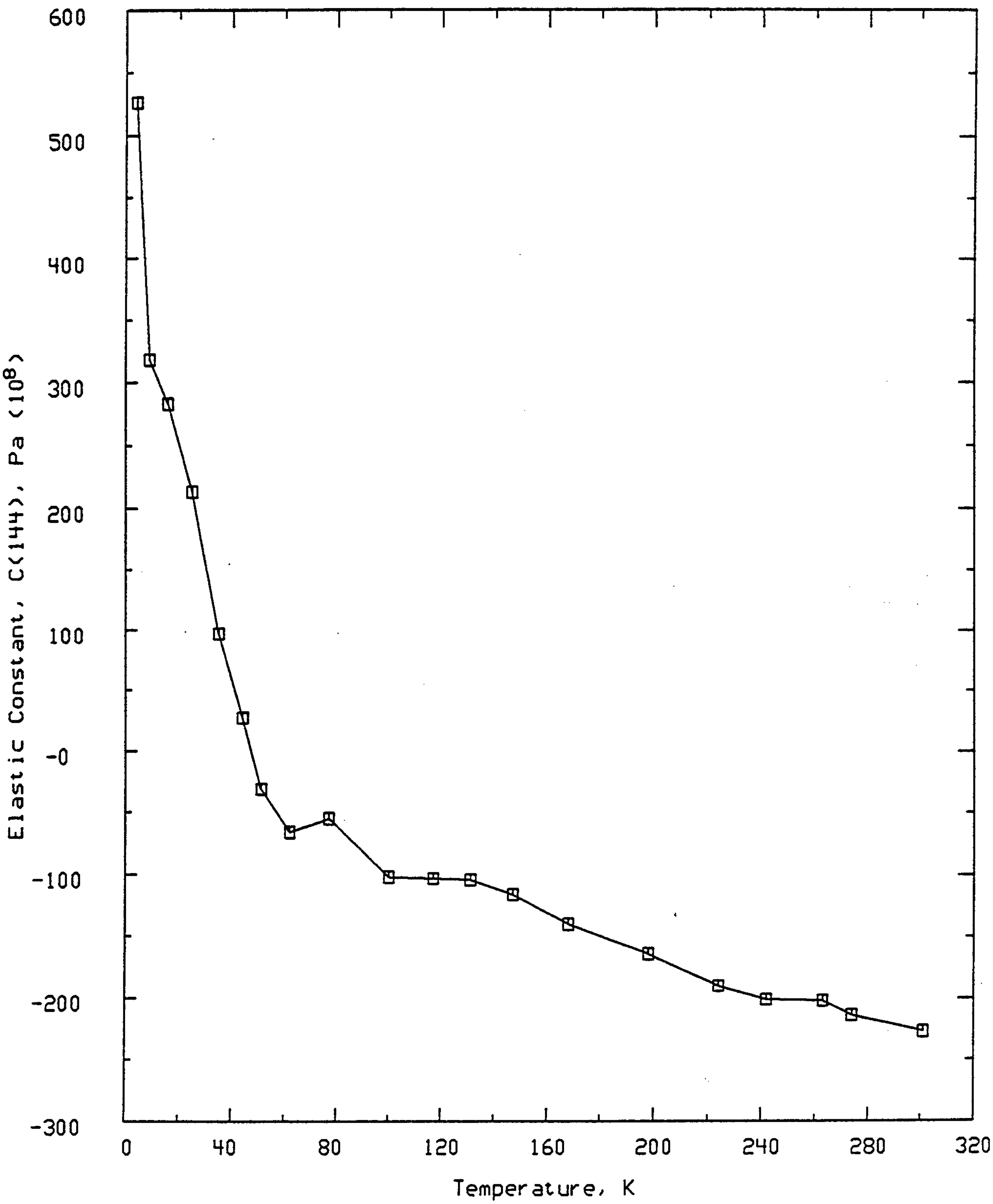

Figure 119 Elastic Constant, C(144) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(166)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 120

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.5214	cm

Additional Identifiers :

Length is average of 2.5171, 2.5222, and 2.5248 cm along [100], [110], and [111] orientations, respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of finite amplitude longitudinal ultrasonic wave.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine nonlinearity parameters.

Parameters-Codified :

Frequency : 30 MHz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(166)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	-3.850e+11	St. dev.=+/-7 GPa
7.700e+01	-3.230e+11	St. dev.=+/-8 GPa
2.980e+02	-2.960e+11	St. dev.=+/-12 GPa

Comments on Data

Data taken from table.
Agreement with theory is good.

Reference

TEMPERATURE VARIATION OF SOME COMBINATIONS OF

THIRD-ORDER ELASTIC CONSTANTS OF SILICON BETWEEN 300 AND 3 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
52 (5), 3383-7, 1981.

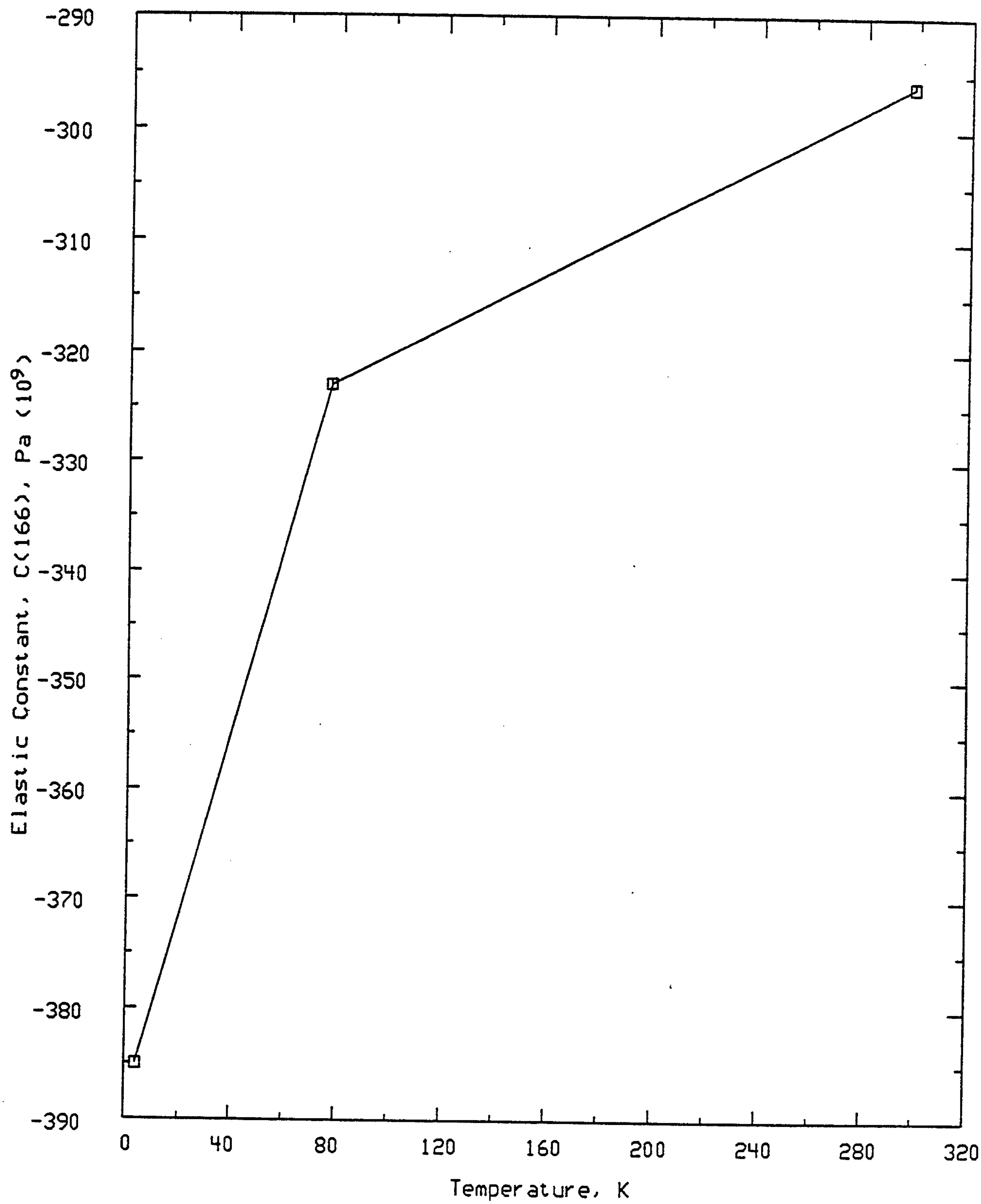

Figure 120 Elastic Constant, C(166) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(166)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 121

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends are lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.539	cm

Additional Identifiers :

Length is average of 2.571, 2.522, and 2.5248 cm in [100] [110], and [111] orientations respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique

Excitation of a finite amplitude longitudinal ultrasonic wave which propegates along the principal crystallographic direction.

Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine the nonlinearity parameter which contain three linear combinations of 3rd order elastic constants.

Parameters-Codified :

Frequency : 30 M Hz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(166)	Pa

Data Points :

X	Y
7.000e+00	-4.000e+10
8.000e+00	-3.810e+10
1.500e+01	-3.750e+10
4.300e+01	-3.560e+10
6.000e+01	-3.340e+10
7.800e+01	-3.240e+10
9.900e+01	-3.240e+10

1.000e+02	-3.240e+10
1.180e+02	-3.230e+10
1.320e+02	-3.230e+10
1.490e+02	-3.230e+10
1.690e+02	-3.160e+10
1.990e+02	-3.160e+10
2.230e+02	-3.160e+10
2.410e+02	-3.150e+10
2.600e+02	-3.090e+10
2.720e+02	-3.090e+10
2.970e+02	-3.080e+10

Comments on Data

Data read from figure 3.

Reference

THIRD-ORDER ELASTIC CONSTANTS AND GRUENEISEN PARAMETERS OF SILICON AND GERMANIUM BETWEEN 3 AND 300 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
54 (2), 752-7, 1983.

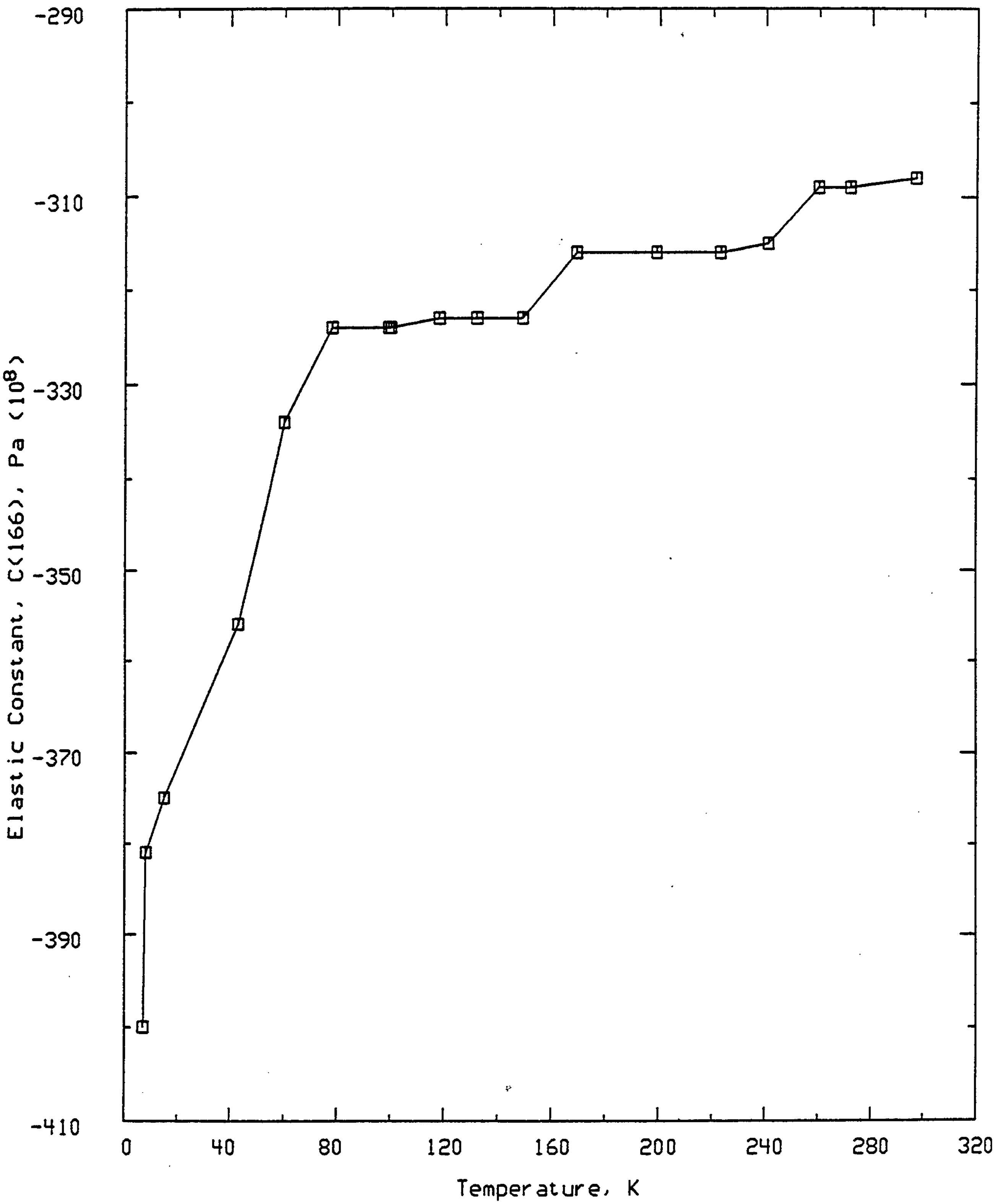

Figure 121 Elastic Constant, C(166) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(456)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 122

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.5214	cm

Additional Identifiers :

Length is average of 2.5171, 2.5222, and 2.5248 cm along [100], [110], and [111] orientations, respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of finite amplitude longitudinal ultrasonic wave.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine nonlinearity parameters.

Parameters-Codified :

Frequency : 30 MHz

Measured/Evaluated Properties

X	: Temperature	K
Y	: Elastic Constant, C(456)	Pa

Data Points :

X	Y	Remarks:
4.000e+00	-4.000e+10	St. dev.=+/-11 GPa
7.700e+01	-2.100e+10	St. dev.=+/-34 GPa
2.980e+02	-7.400e+09	St. dev.=+/-22 GPa

Comments on Data

Data taken from table.
Agreement with theory is good.

Reference

TEMPERATURE VARIATION OF SOME COMBINATIONS OF

THIRD-ORDER ELASTIC CONSTANTS OF SILICON BETWEEN 300 AND 3 DEGREE K.

Philip, J. Breazeale, M. A.

J. APPL. PHYS.

52 (5), 3383-7, 1981.

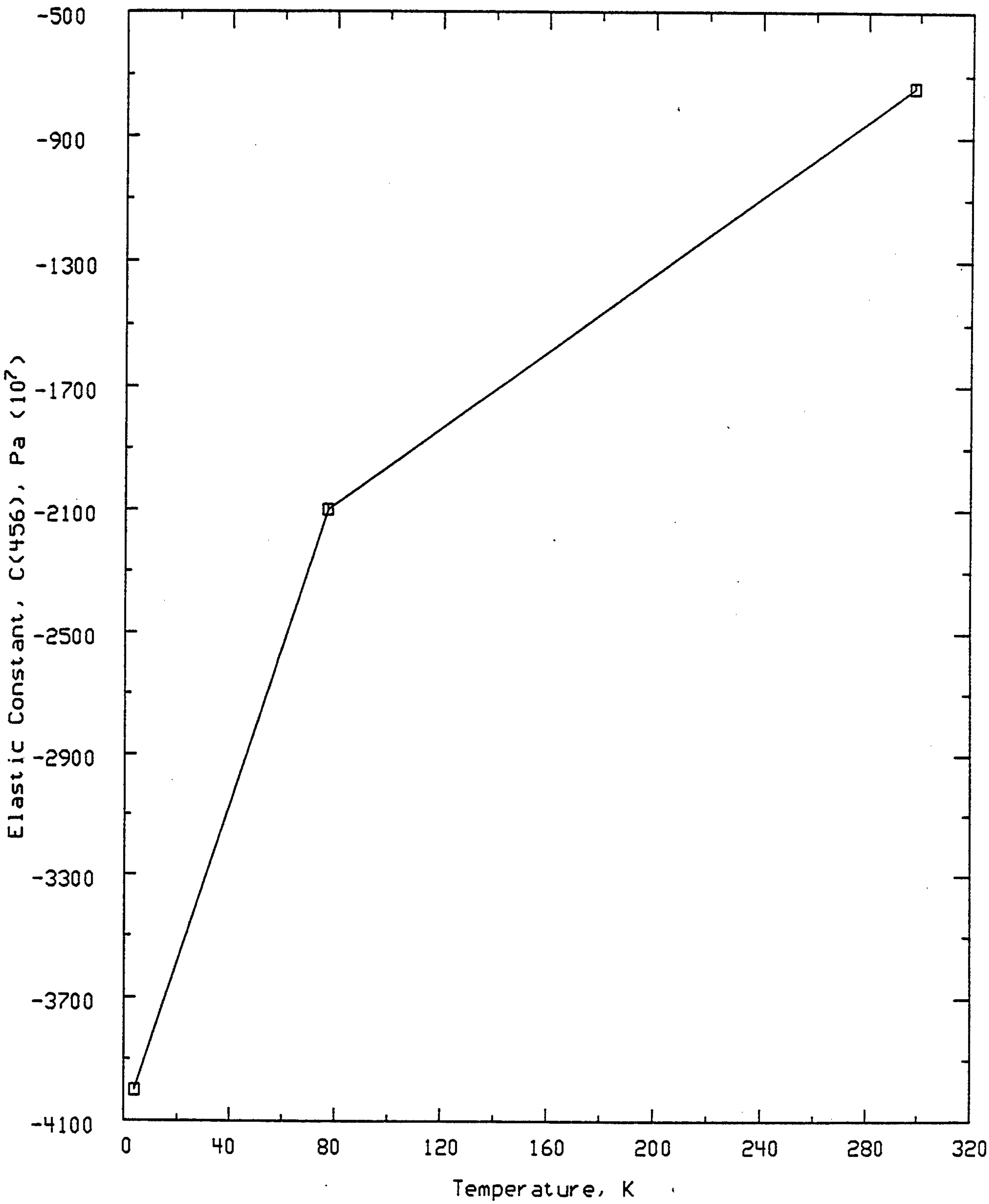

Figure 122 Elastic Constant, C(456) of Silicon

MATERIAL: Silicon

PROPERTY: Elastic Constant, C(456)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 123

****

Descriptors-Textual :

After surface treatment, ends were covered with 0.1 microns of copper to make them conductive.

Additional Preparation/Conditioning

Surface Treatment :

Sample ends are lapped and polished until optically flat and parallel to within 15 inches of arc.

Specimen Identification

Dimensions (Geometry) :

Length	2.539	cm

Additional Identifiers :

Length is average of 2.571, 2.522, and 2.5248 cm in [100] [110], and [111] orientations respectively.

Measurement/Evaluation Method

Name/Description :

Ultrasonic Harmonic Generation Technique
Excitation of a finite amplitude longitudinal ultrasonic wave which propegates along the principal crystallographic direction.
Measurement of fundamental amplitude and the generated second harmonic amplitude used to determine the nonlinearity parameter which contain three linear combinations of 3rd order elastic constants.

Parameters-Codified :

Frequency : 30 M Hz

Measured/Evaluated Properties

X : Temperature	K
Y : Elastic Constant, C(456)	Pa

Data Points :

X	Y
4.000e+00	-2.600e+10
1.000e+01	-3.060e+10
1.700e+01	-3.070e+10
2.500e+01	-3.190e+10
3.600e+01	-3.310e+10
4.500e+01	-3.310e+10
5.200e+01	-3.310e+10

6.100e+01	-3.430e+10
7.700e+01	-3.440e+10
1.000e+02	-3.450e+10
1.190e+02	-3.460e+10
1.320e+02	-3.580e+10
1.490e+02	-3.360e+10
1.690e+02	-3.370e+10
1.990e+02	-3.490e+10
2.240e+02	-3.510e+10
2.420e+02	-3.400e+10
2.610e+02	-3.290e+10
2.720e+02	-3.180e+10
2.990e+02	-3.310e+10

Comments on Data

Data read from figure 4.

Reference

THIRD-ORDER ELASTIC CONSTANTS AND GRUENEISEN PARAMETERS OF SILICON AND GERMANIUM BETWEEN 3 AND 300 DEGREE K.
Philip, J. Breazeale, M. A.
J. APPL. PHYS.
54 (2), 752-7, 1983.

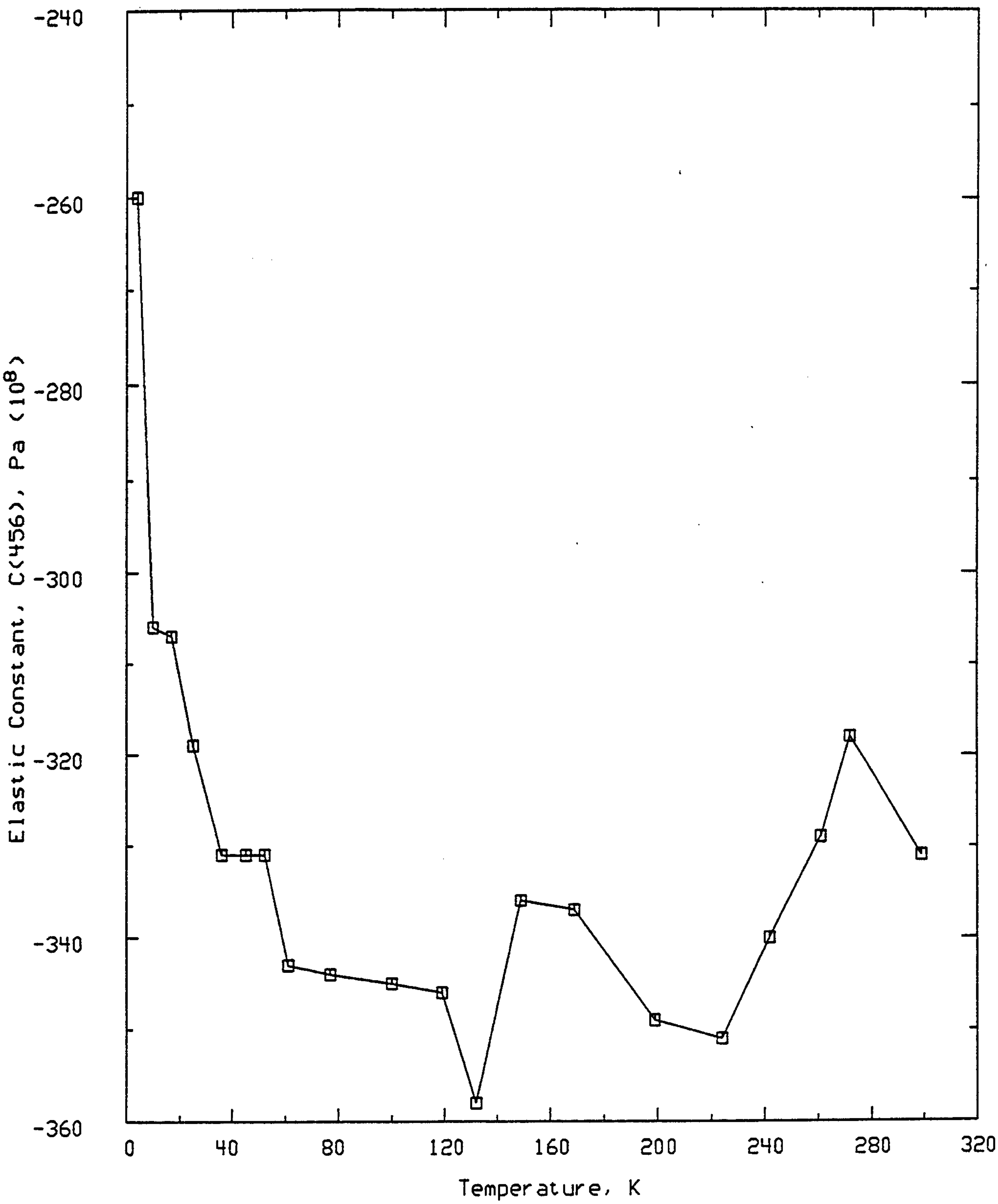

Figure 123 Elastic Constant, C(456) of Silicon

MATERIAL: Silicon

PROPERTY: Tensile Stress

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 124

****

Material Preparation

Crystal Growing Method :

Dislocation-free Czochralski crystals grown in various atmospheres including vacuum, argon, N(2)-5% H(2) or purified hydrogen.

Additional Preparation/Conditioning

Surface Treatment :

Samples prepared by grinding with No. 600 SiC grit etching in CP-4 for 3-5 minutes.

Specimen Identification

Dimensions (Geometry) :

Gauge-Section Length	2.5	cm
Width	1.5	mm
Thickness	3.	mm

Additional Identifiers :

orientation along [001]

Measurement/Evaluation Method

Name/Description :

Tensile Loaded Bar Method

Tested with an Instron machine. A thermocouple placed about 2mm away from the specimen measured the temperature.

Parameters-Codified :

Pressure : 1.0e-03 mm Hg

Measurement Laboratory : Raytheon Company, Research Division

Measured/Evaluated Properties

X	: Cross-Head Displacement	%
Y	: Tensile Stress	Pa
Z1	: Temperature	K
Z2	: Cross-Head Speed	$m\ s^{-1}$

Data Points :

X	Y	Z1	Z2
0.000e+00	0.000e+00	1.288e+03	8.333e-05
3.300e-01	4.031e+07	1.288e+03	8.333e-05
7.000e-01	7.845e+07	1.288e+03	8.333e-05
9.400e-01	1.030e+08	1.288e+03	8.333e-05

9.900e-01	1.049e+08	1.288e+03	8.333e-05
1.030e+00	1.040e+08	1.288e+03	8.333e-05
1.040e+00	7.845e+07	1.288e+03	8.333e-05
1.190e+00	3.982e+07	1.288e+03	8.333e-05
1.190e+00	3.521e+07	1.288e+03	8.333e-05
1.200e+00	3.168e+07	1.288e+03	8.333e-05
1.430e+00	2.824e+07	1.288e+03	8.333e-05
1.710e+00	2.658e+07	1.288e+03	8.333e-05
2.040e+00	2.540e+07	1.288e+03	8.333e-05
2.570e+00	2.481e+07	1.288e+03	8.333e-05
3.040e+00	2.599e+07	1.288e+03	8.333e-05
3.710e+00	2.540e+07	1.288e+03	8.333e-05
4.230e+00	2.599e+07	1.288e+03	8.333e-05

Comments on Data

Data read from Figure 3.
Initial portion essentially linear, at plastic elongation of 0.1-0.2% , stress reaches maximum.

Reference

MACROSCOPIC PLASTIC PROPERTIES OF DISLOCATION-FREE GERMANIUM AND OTHER SEMICONDUCTOR CRYSTALS. I. YIELD BEHAVIOR.
Patel, J. R. Chaudhuri, A. R.
J. APPL. PHYS.
34 (9), 2788-99, 1963.

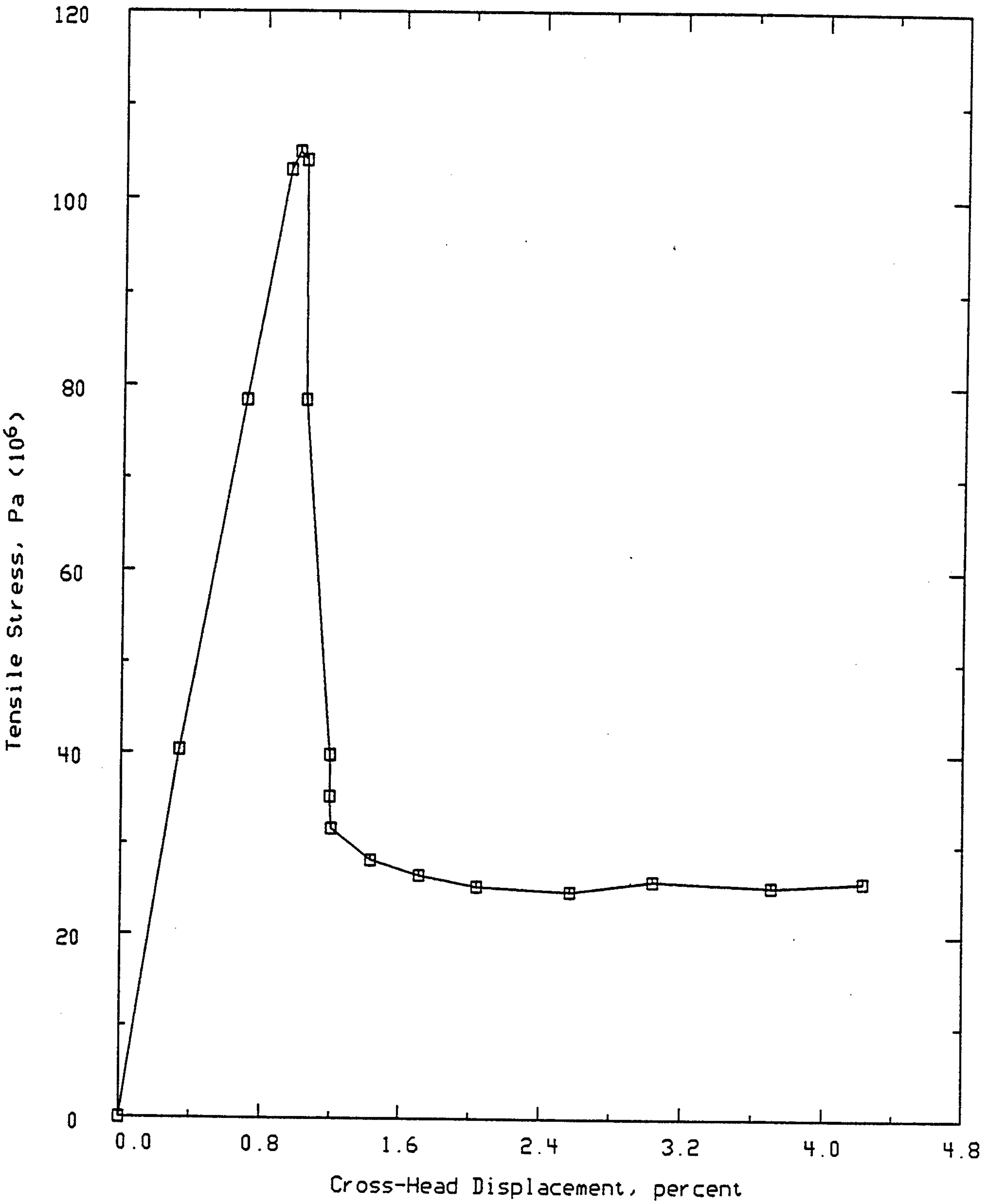

Figure 124 Tensile Stress of Silicon

MATERIAL: Silicon

PROPERTY: Tensile Stress

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 125

****

Material Preparation

Crystal Growing Method :

Dislocation-free Czochralski crystals grown in various atmospheres including vacuum, argon, N(2)-5% H(2) or purified hydrogen.

Additional Preparation/Conditioning

Surface Treatment :

Samples prepared by grinding with No. 600 SiC grit etching in CP-4 for 3-5 minutes.

Specimen Identification

Dimensions (Geometry) :

Gauge-Section Length	2.5	cm
Width	1.5	mm
Thickness	3.	mm

Additional Identifiers :

orientation along [001]

Additional Properties

Other Properties-Textual :

By increasing crystal growth diameter, dislocations from 1e03 to 1e04/cm[2] were incorporated.

Thermal shock was used to obtain dislocations approximately 1e05 per cm[2].

By bending and flattening, dislocations from 1e06 to 1e07 per cm[2] were incorporated.

Measurement/Evaluation Method

Name/Description :

Tensile Loaded Bar Method

Tested with an Instron machine. A thermocouple placed about 2mm away from the specimen measured the temperature.

Parameters-Codified :

Pressure : 1.0e-03 mm Hg

Measurement Laboratory : Raytheon Company, Research Division

Measured/Evaluated Properties

X	: Cross-Head Displacement	%
Y	: Tensile Stress	Pa
Z1	: Dislocation Density	m^{-2}

Z2 : Temperature K
Z3 : Cross-Head Speed $m\ s^{-1}$

Data Points :

X	Y	Z1	Z2	Z3
0.000e+00	0.000e+00	0.000e+00	1.088e+03	8.333e-07
3.200e-01	3.854e+07	0.000e+00	1.088e+03	8.333e-07
5.100e-01	5.806e+07	0.000e+00	1.088e+03	8.333e-07
7.000e-01	7.786e+07	0.000e+00	1.088e+03	8.333e-07
7.600e-01	9.120e+07	0.000e+00	1.088e+03	8.333e-07
7.600e-01	9.238e+07	0.000e+00	1.088e+03	8.333e-07
8.200e-01	9.307e+07	0.000e+00	1.088e+03	8.333e-07
8.500e-01	9.199e+07	0.000e+00	1.088e+03	8.333e-07
9.500e-01	7.786e+07	0.000e+00	1.088e+03	8.333e-07
1.000e+00	5.835e+07	0.000e+00	1.088e+03	8.333e-07
1.070e+00	5.305e+07	0.000e+00	1.088e+03	8.333e-07
1.160e+00	4.619e+07	0.000e+00	1.088e+03	8.333e-07
1.290e+00	4.197e+07	0.000e+00	1.088e+03	8.333e-07
1.470e+00	3.893e+07	0.000e+00	1.088e+03	8.333e-07
1.750e+00	3.550e+07	0.000e+00	1.088e+03	8.333e-07
2.000e+00	3.393e+07	0.000e+00	1.088e+03	8.333e-07
2.250e+00	3.393e+07	0.000e+00	1.088e+03	8.333e-07
2.440e+00	3.472e+07	0.000e+00	1.088e+03	8.333e-07
2.720e+00	3.511e+07	0.000e+00	1.088e+03	8.333e-07
3.000e+00	3.550e+07	0.000e+00	1.088e+03	8.333e-07
3.290e+00	3.511e+07	0.000e+00	1.088e+03	8.333e-07
3.720e+00	3.432e+07	0.000e+00	1.088e+03	8.333e-07
3.970e+00	3.315e+07	0.000e+00	1.088e+03	8.333e-07
4.290e+00	3.197e+07	0.000e+00	1.088e+03	8.333e-07
4.600e+00	3.089e+07	0.000e+00	1.088e+03	8.333e-07
5.000e+00	3.089e+07	0.000e+00	1.088e+03	8.333e-07
5.530e+00	3.089e+07	0.000e+00	1.088e+03	8.333e-07
6.190e+00	3.158e+07	0.000e+00	1.088e+03	8.333e-07
0.000e+00	0.000e+00	1.000e+07	1.088e+03	8.333e-07
3.200e-01	3.854e+07	1.000e+07	1.088e+03	8.333e-07
4.700e-01	5.835e+07	1.000e+07	1.088e+03	8.333e-07
5.700e-01	6.904e+07	1.000e+07	1.088e+03	8.333e-07
6.300e-01	6.943e+07	1.000e+07	1.088e+03	8.333e-07
6.600e-01	6.865e+07	1.000e+07	1.088e+03	8.333e-07
7.600e-01	5.835e+07	1.000e+07	1.088e+03	8.333e-07
8.800e-01	4.540e+07	1.000e+07	1.088e+03	8.333e-07
9.100e-01	4.119e+07	1.000e+07	1.088e+03	8.333e-07
1.040e+00	3.893e+07	1.000e+07	1.088e+03	8.333e-07
1.250e+00	3.854e+07	1.000e+07	1.088e+03	8.333e-07

1.410e+00	3.815e+07	1.000e+07	1.088e+03	8.333e-07
1.690e+00	3.619e+07	1.000e+07	1.088e+03	8.333e-07
2.070e+00	3.354e+07	1.000e+07	1.088e+03	8.333e-07
2.350e+00	3.246e+07	1.000e+07	1.088e+03	8.333e-07
2.690e+00	3.275e+07	1.000e+07	1.088e+03	8.333e-07
3.000e+00	3.354e+07	1.000e+07	1.088e+03	8.333e-07
3.470e+00	3.393e+07	1.000e+07	1.088e+03	8.333e-07
3.820e+00	3.511e+07	1.000e+07	1.088e+03	8.333e-07
3.970e+00	3.619e+07	1.000e+07	1.088e+03	8.333e-07
4.250e+00	3.697e+07	1.000e+07	1.088e+03	8.333e-07
4.570e+00	3.697e+07	1.000e+07	1.088e+03	8.333e-07
5.000e+00	3.697e+07	1.000e+07	1.088e+03	8.333e-07
5.500e+00	3.658e+07	1.000e+07	1.088e+03	8.333e-07
6.190e+00	3.658e+07	1.000e+07	1.088e+03	8.333e-07
0.000e+00	0.000e+00	5.000e+08	1.088e+03	8.333e-07
2.900e-01	3.893e+07	5.000e+08	1.088e+03	8.333e-07
4.100e-01	4.619e+07	5.000e+08	1.088e+03	8.333e-07
5.400e-01	4.697e+07	5.000e+08	1.088e+03	8.333e-07
6.000e-01	4.619e+07	5.000e+08	1.088e+03	8.333e-07
6.600e-01	4.315e+07	5.000e+08	1.088e+03	8.333e-07
7.500e-01	3.893e+07	5.000e+08	1.088e+03	8.333e-07
8.800e-01	3.128e+07	5.000e+08	1.088e+03	8.333e-07
1.000e+00	2.824e+07	5.000e+08	1.088e+03	8.333e-07
1.190e+00	2.599e+07	5.000e+08	1.088e+03	8.333e-07
1.440e+00	2.520e+07	5.000e+08	1.088e+03	8.333e-07
1.970e+00	2.589e+07	5.000e+08	1.088e+03	8.333e-07
2.530e+00	2.628e+07	5.000e+08	1.088e+03	8.333e-07
3.130e+00	2.746e+07	5.000e+08	1.088e+03	8.333e-07
0.000e+00	0.000e+00	1.000e+10	1.088e+03	8.333e-07
1.600e-01	1.952e+07	1.000e+10	1.088e+03	8.333e-07
2.800e-01	3.364e+07	1.000e+10	1.088e+03	8.333e-07
3.500e-01	3.432e+07	1.000e+10	1.088e+03	8.333e-07
4.100e-01	3.364e+07	1.000e+10	1.088e+03	8.333e-07
6.600e-01	3.050e+07	1.000e+10	1.088e+03	8.333e-07
1.000e+00	2.824e+07	1.000e+10	1.088e+03	8.333e-07
1.530e+00	2.824e+07	1.000e+10	1.088e+03	8.333e-07
2.000e+00	2.971e+07	1.000e+10	1.088e+03	8.333e-07
2.350e+00	3.089e+07	1.000e+10	1.088e+03	8.333e-07
2.690e+00	3.207e+07	1.000e+10	1.088e+03	8.333e-07
2.970e+00	3.275e+07	1.000e+10	1.088e+03	8.333e-07
3.500e+00	3.354e+07	1.000e+10	1.088e+03	8.333e-07
3.940e+00	3.393e+07	1.000e+10	1.088e+03	8.333e-07
5.000e+00	3.472e+07	1.000e+10	1.088e+03	8.333e-07
5.540e+00	3.540e+07	1.000e+10	1.088e+03	8.333e-07

6.040e+00	3.579e+07	1.000e+10	1.088e+03	8.333e-07
6.220e+00	3.579e+07	1.000e+10	1.088e+03	8.333e-07

Comments on Data

Data read from Figure 8.

Reference

MACROSCOPIC PLASTIC PROPERTIES OF DISLOCATION-FREE GERMANIUM AND OTHER SEMICONDUCTOR CRYSTALS. I. YIELD BEHAVIOR.
Patel, J. R. Chaudhuri, A. R.
J. APPL. PHYS.
34 (9), 2788-99, 1963.

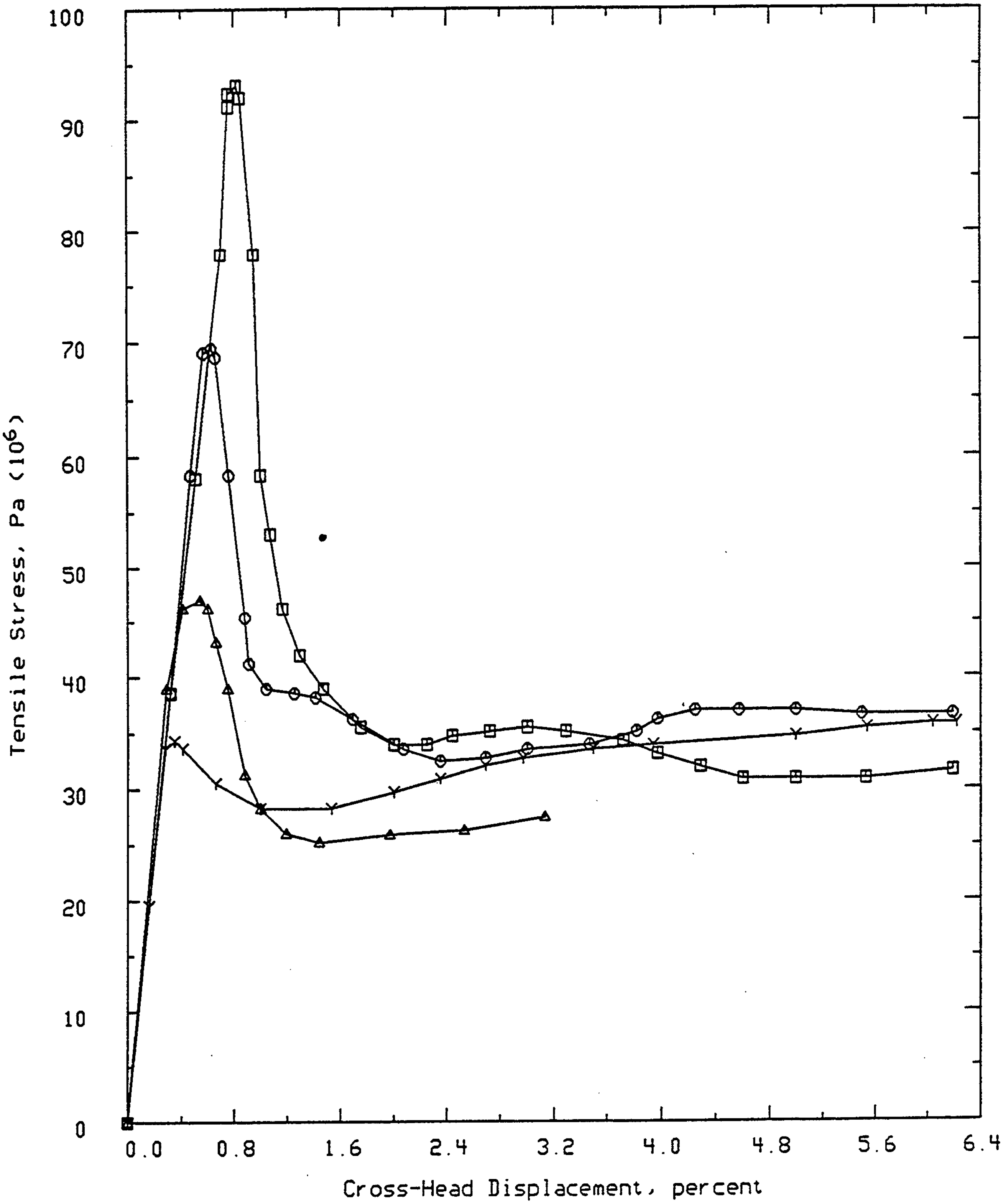

Figure 125 Tensile Stress of Silicon

MATERIAL: Silicon	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Tensile Strength, Lower Yield	DATA SET 126

****

Material Preparation

Crystal Growing Method :

Dislocation-free Czochralski crystals grown in various atmospheres including vacuum, argon, N(2)-5% H(2) or purified hydrogen.

Additional Preparation/Conditioning

Surface Treatment :

Samples prepared by grinding with No. 600 SiC grit and etching in CP-4 for 3-5 minutes.

Specimen Identification

Dimensions (Geometry) :

Gauge-Section Length	2.5	cm
Width	1.5	mm
Thickness	3.	mm

Additional Identifiers :

orientation along [001]

Measurement/Evaluation Method

Name/Description :

Tensile Loaded Bar Method

Tested with an Instron machine. A thermocouple placed about 2mm away from the specimen measured the temperature.

Parameters-Codified :

Pressure : 1.0e-03 mm Hg

Measurement Laboratory : Raytheon Company, Research Division

Measured/Evaluated Properties

X : Temperature	K
Y : Tensile Strength, Lower Yield	Pa
Z1 : Cross-Head Speed	m s^{-1}

Data Points :

X	Y	Z1
1.083e+03	3.207e+07	8.333e-07
1.183e+03	1.412e+07	8.333e-07
1.238e+03	1.138e+07	8.333e-07
1.285e+03	6.374e+06	8.333e-07

Comments on Data

Data was digitized from Figure 14.
Data is called the flow stress in the paper.

Reference

MACROSCOPIC PLASTIC PROPERTIES OF DISLOCATION-FREE GERMANIUM AND OTHER SEMICONDUCTOR CRYSTALS. I. YIELD BEHAVIOR.
Patel, J. R.   Chaudhuri, A. R.
J. APPL. PHYS.
34 (9), 2788-99, 1963.

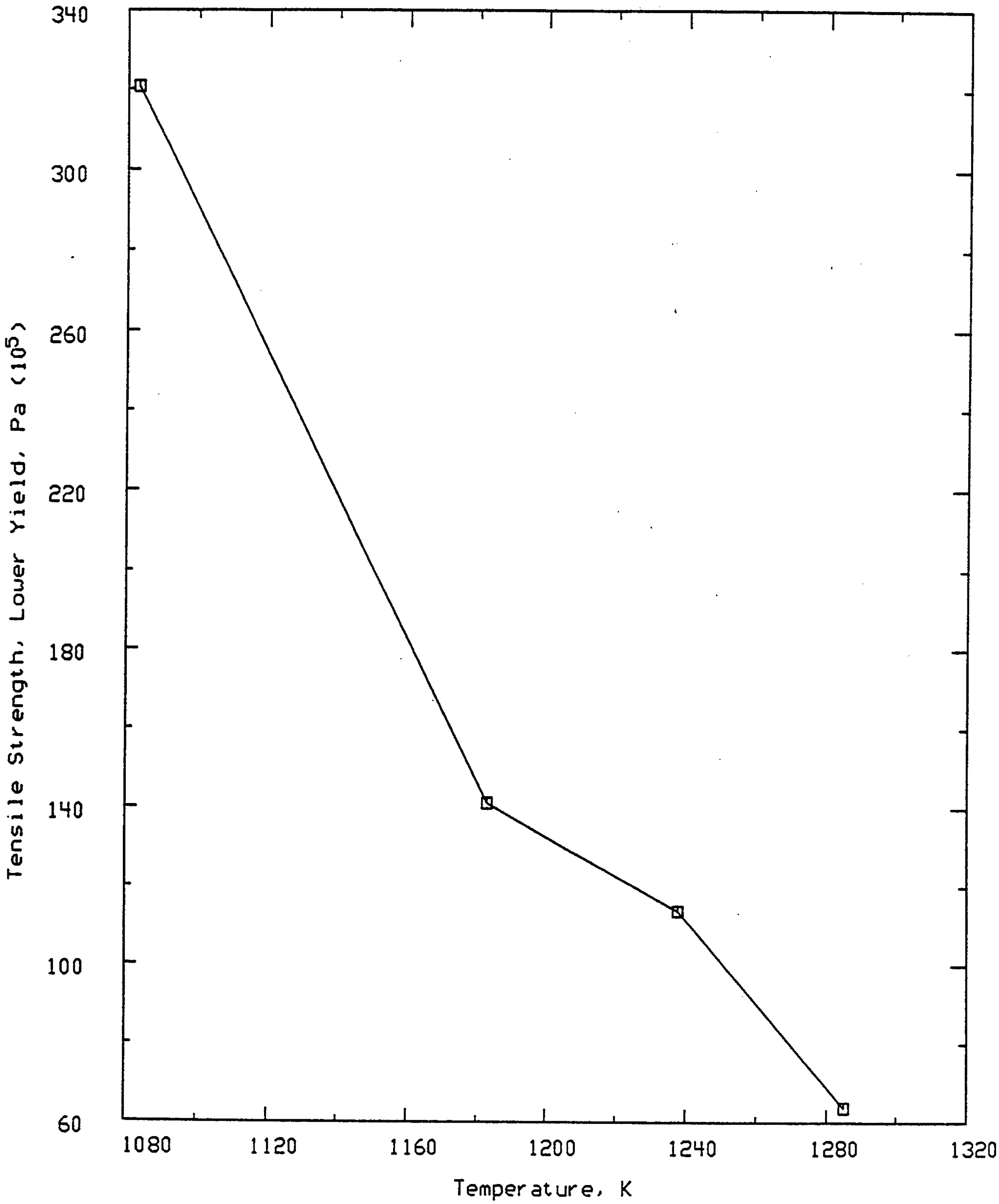

Figure 126 Tensile Strength, Lower Yield of Silicon

MATERIAL: Silicon | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Tensile Strength, Upper Yield | DATA SET 127
****

Material Preparation

Crystal Growing Method :
Dislocation-free Czochralski crystals grown in various atmospheres including vacuum, argon, N(2)-5% H(2) or purified hydrogen.

Additional Preparation/Conditioning

Surface Treatment :
Samples prepared by grinding with No. 600 SiC grit and etching in CP-4 for 3-5 minutes.

Specimen Identification

Dimensions (Geometry) :

Gauge-Section Length	2.5	cm
Width	1.5	mm
Thickness	3.	mm

Additional Identifiers :
orientation along [001]

Measurement/Evaluation Method

Name/Description :
Tensile Loaded Bar Method
Tested with an Instron machine. A thermocouple placed about 2mm away from the specimen measured the temperature.
Parameters-Codified :
Pressure : 1.0e-03 mm Hg
Measurement Laboratory : Raytheon Company, Research Division

Measured/Evaluated Properties

X : Temperature		K
Y : Tensile Strength, Upper Yield		Pa
Z1 : Cross-Head Speed		$m\ s^{-1}$

Data Points :

X	Y	Z1
8.882e+02	6.090e+08	8.333e-07
9.832e+02	3.078e+08	8.333e-07
1.088e+03	9.532e+07	8.333e-07
1.183e+03	4.688e+07	8.333e-07
1.234e+03	3.109e+07	8.333e-07

1.285e+03	1.491e+07	8.333e-07
1.033e+03	3.931e+08	8.333e-06
1.084e+03	2.612e+08	8.333e-06
1.187e+03	8.767e+07	8.333e-06
1.285e+03	4.678e+07	8.333e-06
1.113e+03	5.020e+08	8.333e-05
1.183e+03	2.215e+08	8.333e-05
1.235e+03	1.932e+08	8.333e-05
1.282e+03	1.060e+08	8.333e-05

Comments on Data

Data was digitized from Figure 14.

Reference

MACROSCOPIC PLASTIC PROPERTIES OF DISLOCATION-FREE GERMANIUM AND OTHER SEMICONDUCTOR CRYSTALS. I. YIELD BEHAVIOR.
Patel, J. R.   Chaudhuri, A. R.
J. APPL. PHYS.
34 (9), 2788-99, 1963.

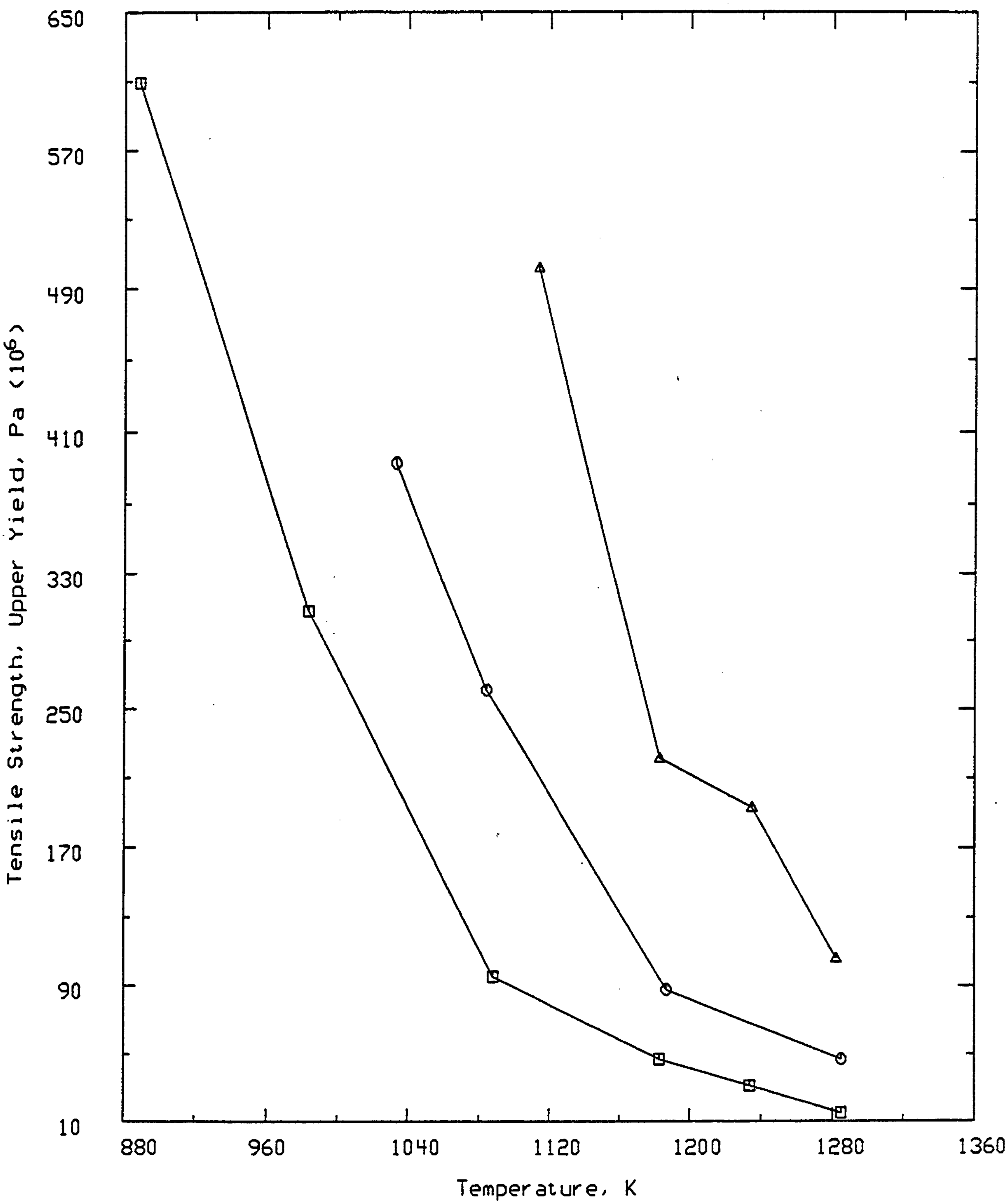

Figure 127 Tensile Strength, Upper Yield of Silicon

MATERIAL: Silicon: As doped

PROPERTY: Compressive Stress

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PURDUE UNIVERSITY
DATA SET 128

****

Material Preparation

Crystal Growing Method :

Czochralski method, dislocation-free.

Additional Preparation/Conditioning

Surface Treatment :

Samples polished mechanically and chemically.

Specimen Identification

Dimensions (Geometry) :

Thickness	2.2	mm
Width	2.2	mm
Length	4.5	mm

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method

Compression test along <111> direction using a relaxometer.

Test done in an atmosphere of spectroscopically pure helium

Accuracy of the yield point measurements was +/- 3 pct.

Parameters-Codified :

Strain Rate : 6.8e-04 s[-1]

Measured/Evaluated Properties

X	: Compressive Strain	%
Y	: Compressive Stress	Pa
Z1	: Dopant Concentration	m^{-3}
Z2	: Temperature	K

Data Points :

X	Y	Z1	Z2
0.000e+00	0.000e+00	1.000e+22	1.073e+03
3.200e-01	7.951e+07	1.000e+22	1.073e+03
6.200e-01	1.591e+08	1.000e+22	1.073e+03
7.800e-01	1.935e+08	1.000e+22	1.073e+03
8.200e-01	1.961e+08	1.000e+22	1.073e+03
9.000e-01	1.961e+08	1.000e+22	1.073e+03
1.440e+00	1.697e+08	1.000e+22	1.073e+03
1.500e+00	1.670e+08	1.000e+22	1.073e+03

1.680e+00	1.723e+08	1.000e+22	1.073e+03
0.000e+00	0.000e+00	2.000e+25	1.073e+03
5.600e-01	1.392e+08	2.000e+25	1.073e+03
6.200e-01	1.471e+08	2.000e+25	1.073e+03
7.000e-01	1.485e+08	2.000e+25	1.073e+03
7.600e-01	1.457e+08	2.000e+25	1.073e+03
1.160e+00	1.047e+08	2.000e+25	1.073e+03
1.200e+00	1.021e+08	2.000e+25	1.073e+03
1.260e+00	1.021e+08	2.000e+25	1.073e+03
1.420e+00	1.047e+08	2.000e+25	1.073e+03
0.000e+00	0.000e+00	1.000e+26	1.073e+03
4.200e-01	1.060e+08	1.000e+26	1.073e+03
5.400e-01	1.140e+08	1.000e+26	1.073e+03
5.800e-01	1.153e+08	1.000e+26	1.073e+03
6.200e-01	1.140e+08	1.000e+26	1.073e+03
9.600e-01	8.879e+07	1.000e+26	1.073e+03
1.020e+00	8.879e+07	1.000e+26	1.073e+03
1.160e+00	9.144e+07	1.000e+26	1.073e+03
0.000e+00	0.000e+00	1.500e+26	1.073e+03
3.600e-01	8.482e+07	1.500e+26	1.073e+03
4.200e-01	9.011e+07	1.500e+26	1.073e+03
4.600e-01	9.144e+07	1.500e+26	1.073e+03
5.400e-01	9.011e+07	1.500e+26	1.073e+03
6.000e-01	8.350e+07	1.500e+26	1.073e+03
6.400e-01	8.084e+07	1.500e+26	1.073e+03
7.800e-01	8.350e+07	1.500e+26	1.073e+03

Comments on Data

As-doping lowers the upper and lower yield points of silicon.
Dopant concentration determined by Hall effect measuremment.

Reference

SOME MECHANICAL PROPERTIES OF STRONGLY DOPED SILICON SINGLE CRYSTALS.
Mil'vidskii, M. G. Stolyarov, O. G.
Berkova, A. V.
FIZ. TVERD. TELA (LENINGRAD)
6 (10), 3170-2, 1964.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE,
6 (10), 2531-2, 1965)

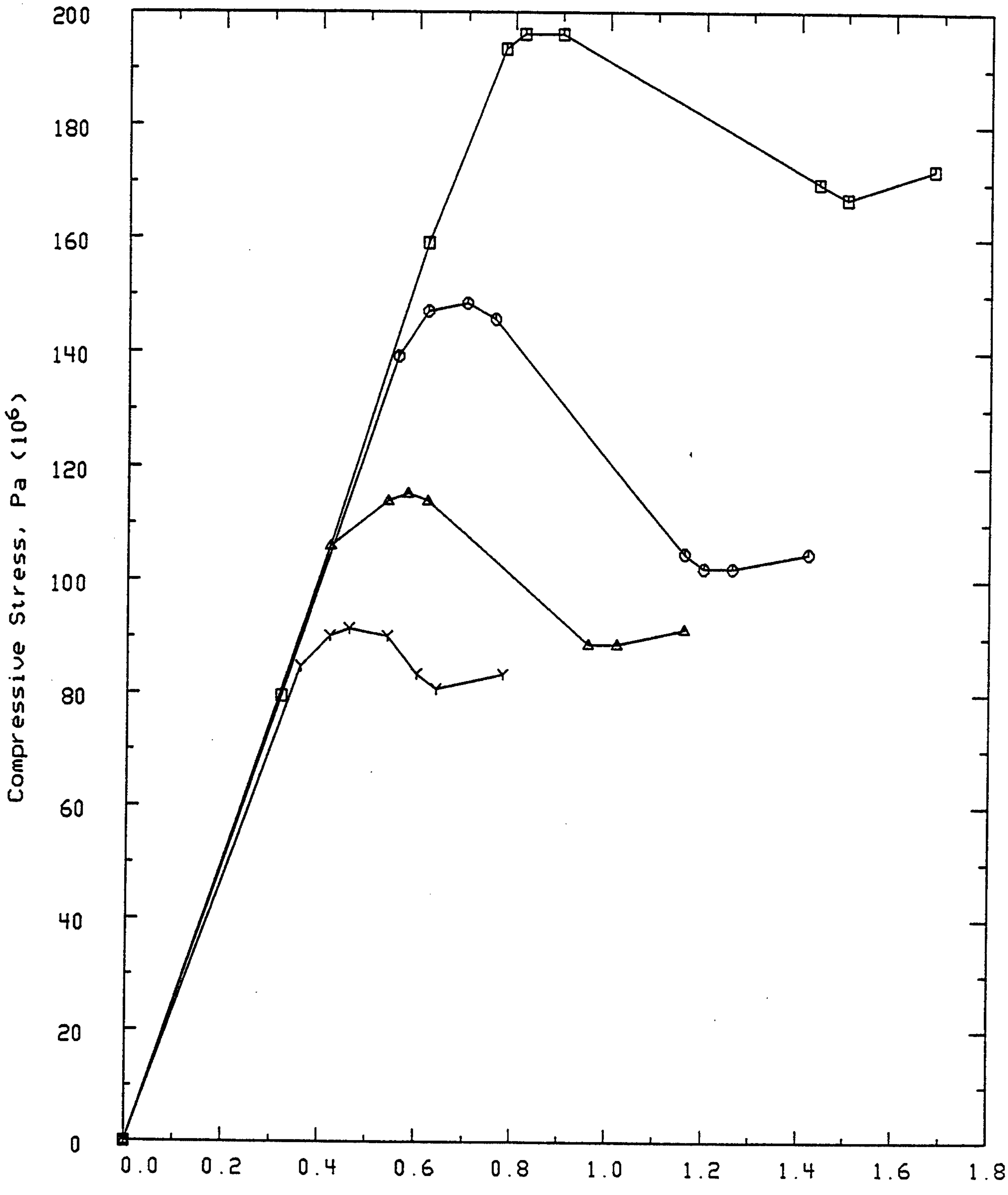

Figure 128 Compressive Stress of Silicon: As doped

MATERIAL: Silicon: B doped

PROPERTY: Compressive Stress

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PURDUE UNIVERSITY
DATA SET 129

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Composition

7.5e17	cm^{-3}	Oxygen Concentration
10.6e16	cm^{-3}	Carbon Concentration

Material Preparation

Crystal Growing Method :
Czochralski-grown, dislocation-free
Descriptors-Textual :
Single-step annealing: 1073 K for 240 hrs

Specimen Identification

Number/Name : cz-b
Dimensions (Geometry) :

Length	10.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	26.6	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Tests performed in air on an Instron machine (TTCM-L)
Parameters-Codified :
Annealing Temperature : 1073. K
Annealing Time : 1-250 hrs.
Strain Rate : 8.3e-05 s[-1]
Temperature : 1073. K (test temperature)

Original Source Reference/Additional Information

Dopant concentration of P or B not given

Measured/Evaluated Properties

X : Compressive Strain	%
Y : Compressive Stress	Pa
Z1 : Temperature	K
Z2 : Strain Rate	s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
0.000e+00	0.000e+00	1.073e+03	8.300e-05	as-received
2.700e-01	5.030e+07	1.073e+03	8.300e-05	
5.400e-01	1.000e+08	1.073e+03	8.300e-05	
7.000e-01	1.147e+08	1.073e+03	8.300e-05	
7.900e-01	1.193e+08	1.073e+03	8.300e-05	
8.600e-01	1.147e+08	1.073e+03	8.300e-05	
9.300e-01	1.007e+08	1.073e+03	8.300e-05	
1.080e+00	8.130e+07	1.073e+03	8.300e-05	
1.230e+00	7.350e+07	1.073e+03	8.300e-05	
1.470e+00	6.890e+07	1.073e+03	8.300e-05	
1.860e+00	6.650e+07	1.073e+03	8.300e-05	
2.100e+00	6.650e+07	1.073e+03	8.300e-05	
2.250e+00	6.340e+07	1.073e+03	8.300e-05	
2.570e+00	6.100e+07	1.073e+03	8.300e-05	
2.810e+00	6.020e+07	1.073e+03	8.300e-05	
3.040e+00	6.020e+07	1.073e+03	8.300e-05	
3.600e+00	5.630e+07	1.073e+03	8.300e-05	
3.910e+00	5.400e+07	1.073e+03	8.300e-05	
4.460e+00	5.160e+07	1.073e+03	8.300e-05	
5.180e+00	5.230e+07	1.073e+03	8.300e-05	
5.890e+00	5.390e+07	1.073e+03	8.300e-05	
7.090e+00	6.150e+07	1.073e+03	8.300e-05	
8.040e+00	6.690e+07	1.073e+03	8.300e-05	
9.790e+00	7.690e+07	1.073e+03	8.300e-05	
0.000e+00	0.000e+00	1.073e+03	8.300e-05	annealed
3.400e-01	5.030e+07	1.073e+03	8.300e-05	
5.200e-01	6.970e+07	1.073e+03	8.300e-05	
6.800e-01	7.590e+07	1.073e+03	8.300e-05	
8.300e-01	7.200e+07	1.073e+03	8.300e-05	
9.900e-01	6.580e+07	1.073e+03	8.300e-05	
1.380e+00	5.960e+07	1.073e+03	8.300e-05	
1.850e+00	5.570e+07	1.073e+03	8.300e-05	
2.800e+00	5.020e+07	1.073e+03	8.300e-05	
3.270e+00	4.860e+07	1.073e+03	8.300e-05	
3.910e+00	5.090e+07	1.073e+03	8.300e-05	
5.020e+00	5.860e+07	1.073e+03	8.300e-05	
5.980e+00	6.390e+07	1.073e+03	8.300e-05	
7.970e+00	7.620e+07	1.073e+03	8.300e-05	
9.560e+00	8.460e+07	1.073e+03	8.300e-05	

Comments on Data

Data was digitized from figure 5.
Upper yield point drastically reduced after annealing.

Reference

COMPRESSION TESTS OF HEAT-TREATED CZOCHRALSKI-GROWN SILICON CRYSTALS.
Yasutake, K. Umeno, M. Kawabe, H.
PHYS. STATUS SOLIDI A
69, 333-41, 1982.

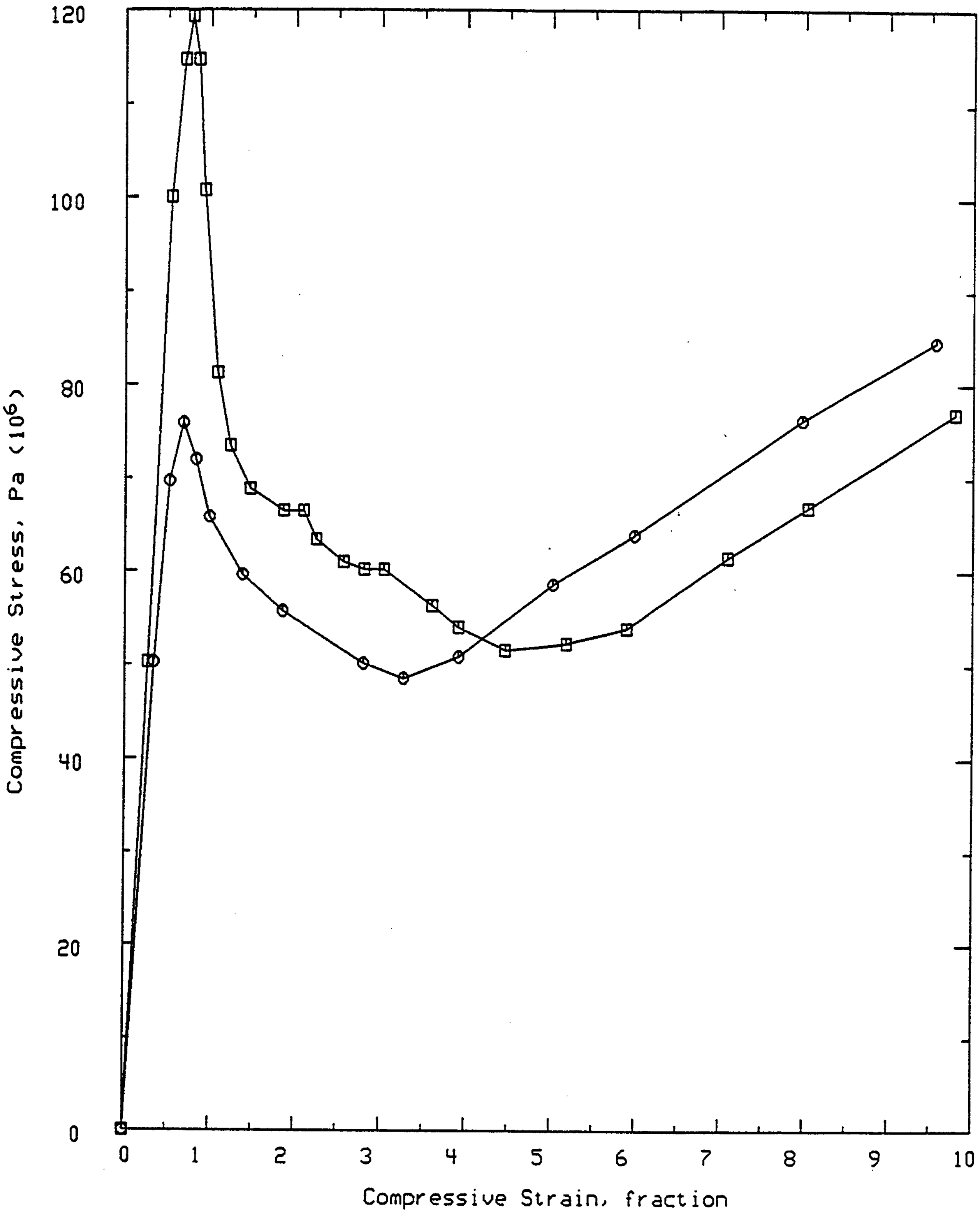

Figure 129 Compressive Stress of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Compressive Stress

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PURDUE UNIVERSITY
DATA SET 130

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Material Preparation

Crystal Growing Method :

Czochralski method, dislocation-free.

Additional Preparation/Conditioning

Surface Treatment :

Samples polished mechanically and chemically.

Specimen Identification

Dimensions (Geometry) :

Thickness	2.2	mm
Width	2.2	mm
Length	4.5	mm

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Compression test along <111> direction using a relaxometer.
Test done in an atmosphere of spectroscopically pure helium
Accuracy of the yield point measurements was +/- 3 pct.

Parameters-Codified :

Strain Rate : 6.8e-04 s[-1]

Measured/Evaluated Properties

X : Compressive Strain	%
Y : Compressive Stress	Pa
Z1 : Dopant Concentration	m^{-3}
Z2 : Temperature	K

Data Points :

X	Y	Z1	Z2	Remarks:
0.000e+00	0.000e+00	5.000e+23	1.073e+03	range 5e17-1e19 cm[-3]
1.031e+00	2.355e+08	5.000e+23	1.073e+03	
1.078e+00	2.386e+08	5.000e+23	1.073e+03	
1.102e+00	2.403e+08	5.000e+23	1.073e+03	
1.172e+00	2.386e+08	5.000e+23	1.073e+03	
1.643e+00	2.037e+08	5.000e+23	1.073e+03	
1.691e+00	2.005e+08	5.000e+23	1.073e+03	
1.714e+00	2.005e+08	5.000e+23	1.073e+03	

1.738e+00	2.005e+08	5.000e+23	1.073e+03
1.808e+00	2.021e+08	5.000e+23	1.073e+03
0.000e+00	0.000e+00	2.000e+22	1.073e+03
8.905e-01	2.036e+08	2.000e+22	1.073e+03
9.375e-01	2.053e+08	2.000e+22	1.073e+03
9.845e-01	2.068e+08	2.000e+22	1.073e+03
1.032e+00	2.053e+08	2.000e+22	1.073e+03
1.055e+00	2.053e+08	2.000e+22	1.073e+03
1.526e+00	1.702e+08	2.000e+22	1.073e+03
1.573e+00	1.687e+08	2.000e+22	1.073e+03
1.621e+00	1.687e+08	2.000e+22	1.073e+03
1.668e+00	1.703e+08	2.000e+22	1.073e+03
0.000e+00	0.000e+00	2.000e+21	1.073e+03
8.437e-01	1.893e+08	2.000e+21	1.073e+03
8.907e-01	1.925e+08	2.000e+21	1.073e+03
9.377e-01	1.941e+08	2.000e+21	1.073e+03
9.612e-01	1.941e+08	2.000e+21	1.073e+03
9.848e-01	1.925e+08	2.000e+21	1.073e+03
1.479e+00	1.607e+08	2.000e+21	1.073e+03
1.527e+00	1.592e+08	2.000e+21	1.073e+03
1.574e+00	1.592e+08	2.000e+21	1.073e+03
1.597e+00	1.592e+08	2.000e+21	1.073e+03
1.668e+00	1.623e+08	2.000e+21	1.073e+03

Comments on Data

B-doping increases the upper and lower yield points of silicon.
Dopant concentration determined by Hall effect measuremment.

Reference

SOME MECHANICAL PROPERTIES OF STRONGLY DOPED SILICON SINGLE CRYSTALS.
Mil'vidskii, M. G. Stolyarov, O. G.
Berkova, A. V.
FIZ. TVERD. TELA (LENINGRAD)
6 (10), 3170-2, 1964.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE,
6 (10), 2531-2, 1965)

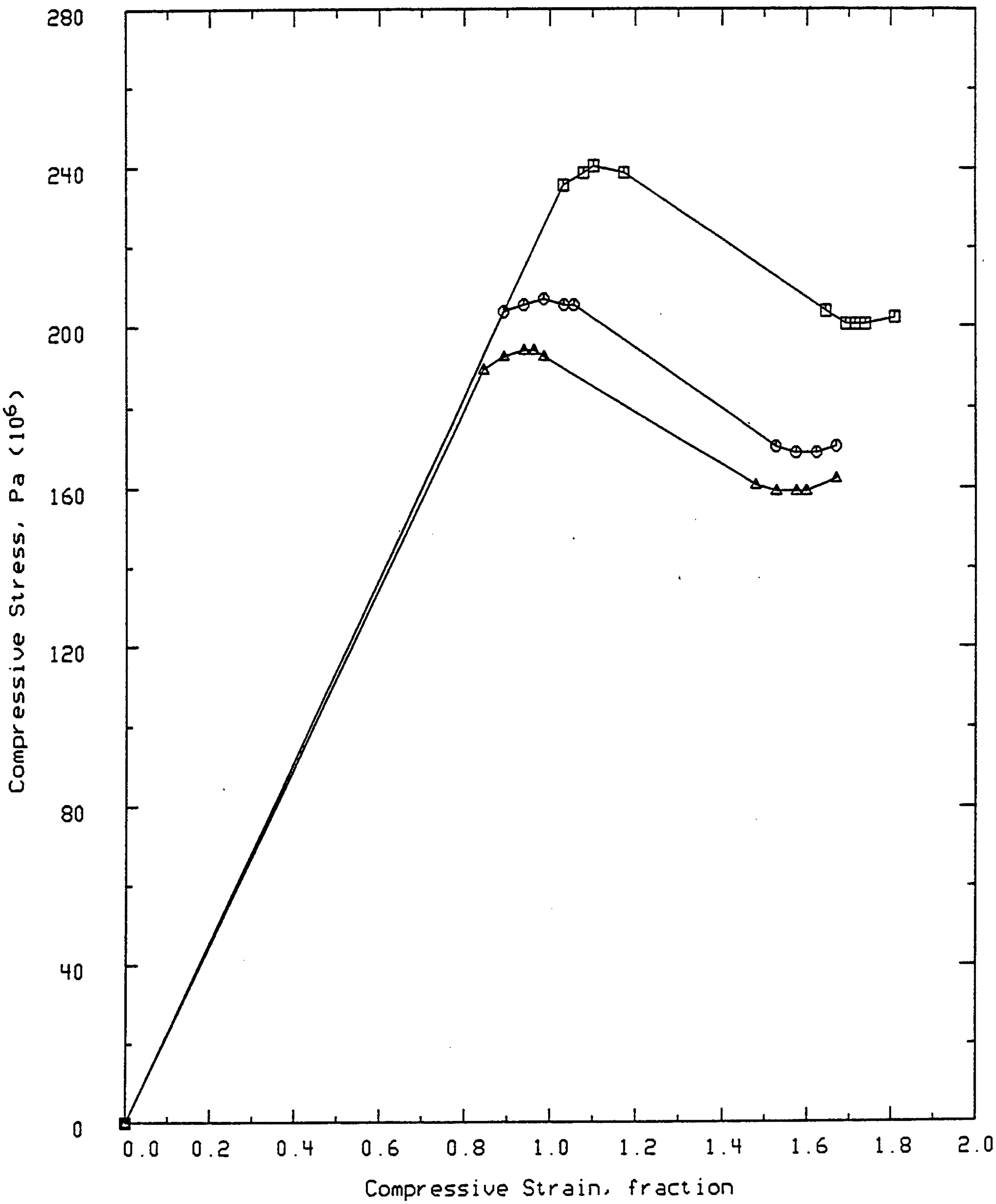

Figure 130 Compressive Stress of Silicon: B doped

MATERIAL: Silicon: P doped

PROPERTY: Compressive Stress

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DATA SET 131

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Composition

1.0E13	cm^{-3}	Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :

Floating-zone-grown boule, n-type

Additional Preparation/Conditioning

Surface Treatment :

Mechanically polished with one face remaining as-ground.
The specimens were cut using a diamond saw.

Specimen Identification

Dimensions (Geometry) :

Length	9.2	mm
Width	3.8	mm
Thickness	3.8	mm

Orientation With Respect To Material : [100] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	700.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Silicon single crystals were deformed in compression at constant strain rates under hydrostatic pressure of 1500 MPa in a solid-confining-medium apparatus.

Parameters-Textual :

The specimen is in contact with a silver jacket. The diffusivity of silver in silicon is so small that during an experiment at the highest temperature (873 K) the penetration of silver is less than one micrometer.
Deformation below 673 K achieved by predeformation at a slower strain rate and temperature above 673 K to eliminate upper yield point. Normal testing then resumed after cooling to desired temperature.

Measured/Evaluated Properties

X	: Compressive Strain	fraction
Y	: Compressive Stress	Pa
Z1	: Temperature	K
Z2	: Strain Rate	s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
3.000e-03	2.500e+08	6.730e+02	5.000e-05	
5.000e-03	4.600e+08	6.730e+02	5.000e-05	
7.000e-03	6.400e+08	6.730e+02	5.000e-05	
8.000e-03	8.100e+08	6.730e+02	5.000e-05	
9.000e-03	9.800e+08	6.730e+02	5.000e-05	
1.100e-02	1.150e+09	6.730e+02	5.000e-05	
1.300e-02	1.330e+09	6.730e+02	5.000e-05	
1.400e-02	1.520e+09	6.730e+02	5.000e-05	
1.600e-02	1.680e+09	6.730e+02	5.000e-05	
1.700e-02	1.880e+09	6.730e+02	5.000e-05	
1.900e-02	2.050e+09	6.730e+02	5.000e-05	
2.100e-02	2.210e+09	6.730e+02	5.000e-05	
2.200e-02	2.390e+09	6.730e+02	5.000e-05	
2.400e-02	2.550e+09	6.730e+02	5.000e-05	
2.700e-02	2.710e+09	6.730e+02	5.000e-05	
3.300e-02	2.730e+09	6.730e+02	5.000e-05	failure
3.000e-03	2.000e+08	6.730e+02	5.000e-06	
7.000e-03	6.000e+08	6.730e+02	5.000e-06	
9.000e-03	7.400e+08	6.730e+02	5.000e-06	
1.100e-02	9.000e+08	6.730e+02	5.000e-06	
1.300e-02	1.090e+09	6.730e+02	5.000e-06	
1.500e-02	1.240e+09	6.730e+02	5.000e-06	
1.800e-02	1.450e+09	6.730e+02	5.000e-06	
2.100e-02	1.630e+09	6.730e+02	5.000e-06	
2.600e-02	1.630e+09	6.730e+02	5.000e-06	
3.100e-02	1.510e+09	6.730e+02	5.000e-06	
3.500e-02	1.390e+09	6.730e+02	5.000e-06	
4.000e-02	1.280e+09	6.730e+02	5.000e-06	
4.600e-02	1.160e+09	6.730e+02	5.000e-06	
5.200e-02	1.090e+09	6.730e+02	5.000e-06	
5.900e-02	1.020e+09	6.730e+02	5.000e-06	
6.600e-02	9.800e+08	6.730e+02	5.000e-06	
7.400e-02	9.800e+08	6.730e+02	5.000e-06	
8.100e-02	9.900e+08	6.730e+02	5.000e-06	
8.900e-02	1.010e+09	6.730e+02	5.000e-06	
9.600e-02	1.020e+09	6.730e+02	5.000e-06	
1.030e-01	1.050e+09	6.730e+02	5.000e-06	

4.000e-03	3.200e+08	5.730e+02	5.000e-06	**
8.000e-03	4.800e+08	5.730e+02	5.000e-06	
1.100e-02	6.400e+08	5.730e+02	5.000e-06	
1.300e-02	8.000e+08	5.730e+02	5.000e-06	
1.600e-02	9.500e+08	5.730e+02	5.000e-06	
2.400e-02	9.200e+08	5.730e+02	5.000e-06	
3.000e-02	8.300e+08	5.730e+02	5.000e-06	
3.600e-02	7.700e+08	5.730e+02	5.000e-06	
4.400e-02	7.400e+08	5.730e+02	5.000e-06	
5.100e-02	7.100e+08	5.730e+02	5.000e-06	
5.800e-02	6.800e+08	5.730e+02	5.000e-06	
6.600e-02	6.600e+08	5.730e+02	5.000e-06	
7.400e-02	6.300e+08	5.730e+02	5.000e-06	
8.000e-02	6.600e+08	5.730e+02	5.000e-06	
9.800e-02	1.900e+08	5.730e+02	5.000e-06	**
9.800e-02	3.700e+08	5.730e+02	5.000e-06	
9.800e-02	5.600e+08	5.730e+02	5.000e-06	
9.800e-02	7.300e+08	5.730e+02	5.000e-06	
9.800e-02	9.000e+08	5.730e+02	5.000e-06	
9.900e-02	1.080e+09	5.730e+02	5.000e-06	
1.000e-01	1.260e+09	5.730e+02	5.000e-06	
1.010e-01	1.450e+09	5.730e+02	5.000e-06	
1.030e-01	1.630e+09	5.730e+02	5.000e-06	
1.050e-01	1.790e+09	5.730e+02	5.000e-06	
1.060e-01	1.970e+09	5.730e+02	5.000e-06	
1.100e-01	2.110e+09	5.730e+02	5.000e-06	
1.150e-01	2.250e+09	5.730e+02	5.000e-06	
1.220e-01	2.350e+09	5.730e+02	5.000e-06	
1.280e-01	2.400e+09	5.730e+02	5.000e-06	
1.340e-01	2.440e+09	5.730e+02	5.000e-06	
1.410e-01	2.480e+09	5.730e+02	5.000e-06	
3.000e-03	1.400e+08	7.730e+02	5.000e-05	
6.000e-03	3.200e+08	7.730e+02	5.000e-05	
1.000e-02	5.300e+08	7.730e+02	5.000e-05	
1.300e-02	6.900e+08	7.730e+02	5.000e-05	
1.600e-02	8.300e+08	7.730e+02	5.000e-05	
2.000e-02	9.800e+08	7.730e+02	5.000e-05	
2.700e-02	1.020e+09	7.730e+02	5.000e-05	
3.400e-02	8.900e+08	7.730e+02	5.000e-05	
4.700e-02	7.500e+08	7.730e+02	5.000e-05	
5.400e-02	7.100e+08	7.730e+02	5.000e-05	
6.100e-02	7.000e+08	7.730e+02	5.000e-05	
6.900e-02	7.000e+08	7.730e+02	5.000e-05	

Comments on Data

** predeformation run at 723 K followed by deformation at 573 K
Data was digitized from Figure 1.
Flow stress drops after a maximum and reaches an easy-glide stage after 5 percent strain. A specimen deformed at 673 K fails shortly after the maximum in the stress-strain curve. This gives a rough value of 2800 MPa of the flow-stress under 1500 MPa hydrostatic pressure. Extrapolation of flow-stress values to a failure stress of 2800 MPa showed that it is not likely to be possible to induce deformation below 548 K under these testing conditions.

Reference

THE PLASTIC DEFORMATION OF SILICON BETWEEN 300 DEGREE C AND 600 DEGREE C.
Castaing, J. Veyssiere, P. Kubin, L. P.
Rabier, J.
PHILOS. MAG. A
44 (6), 1407-13, 1981.

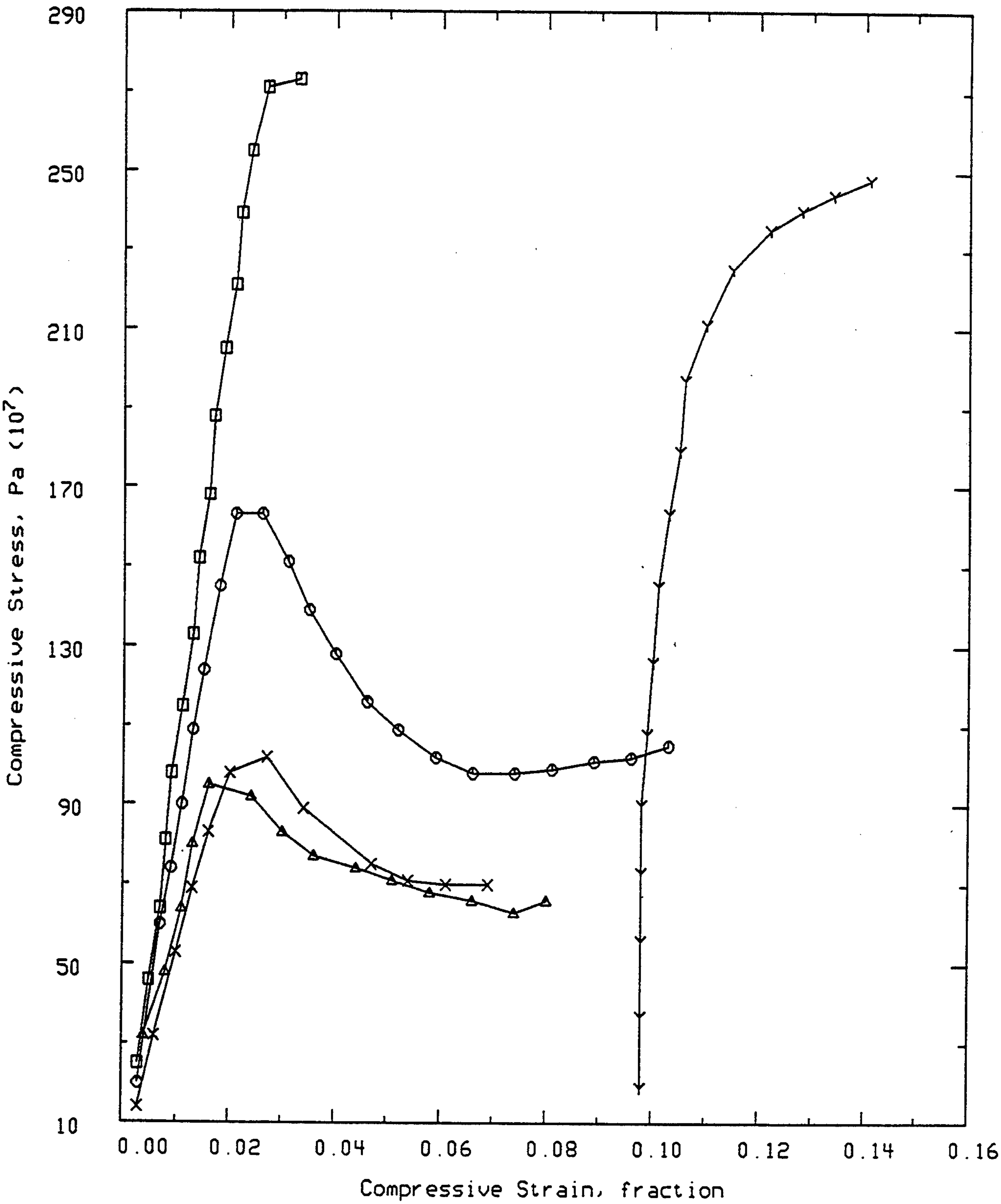

Figure 131 Compressive Stress of Silicon: P doped

MATERIAL: Silicon

PROPERTY: Compressive Stress

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DATA SET 132

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Material Preparation

Crystal Growing Method :
Crucible-grown Czochralski, dislocation-free
Descriptors-Textual :
One specimen was annealed in hydrogen for 4 hrs. at 973 K followed by 30 hrs. at 1273 K

Additional Preparation/Conditioning

Surface Treatment :
Specimens ground and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	0.5	cm
Width	0.5	cm
Thickness	1.25	cm

Orientation With Respect To Material : [123] Direction

Additional Properties

Other Properties-Numerical :

Oxygen Concentration	5.-8.e17	cm^{-3}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Test equipment not specified, probably Instron machine.
Tests done under forming gas (mixture of N(2) and H(2)).
Parameters-Codified :
Strain Rate : 6.7e-05 s[-1]

Measured/Evaluated Properties

X	: Compressive Strain	%
Y	: Compressive Stress	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1	Remarks:
0.000e+00	7.026e+07	1.073e+03	as-grown
1.000e-02	7.514e+07	1.073e+03	

1.100e-01	8.042e+07	1.073e+03	
2.100e-01	8.488e+07	1.073e+03	
3.000e-01	8.852e+07	1.073e+03	
3.500e-01	8.972e+07	1.073e+03	
4.000e-01	9.010e+07	1.073e+03	
4.800e-01	8.882e+07	1.073e+03	
5.000e-01	8.799e+07	1.073e+03	
5.800e-01	8.260e+07	1.073e+03	
6.200e-01	7.806e+07	1.073e+03	
6.700e-01	7.229e+07	1.073e+03	
7.300e-01	6.569e+07	1.073e+03	
8.100e-01	6.112e+07	1.073e+03	
8.700e-01	5.779e+07	1.073e+03	
9.300e-01	5.529e+07	1.073e+03	
1.000e+00	5.279e+07	1.073e+03	
1.060e+00	5.017e+07	1.073e+03	
1.160e+00	4.900e+07	1.073e+03	
1.260e+00	4.771e+07	1.073e+03	
1.340e+00	4.684e+07	1.073e+03	
1.470e+00	4.636e+07	1.073e+03	
1.570e+00	4.630e+07	1.073e+03	
1.640e+00	4.585e+07	1.073e+03	
1.740e+00	4.579e+07	1.073e+03	
1.940e+00	4.567e+07	1.073e+03	
2.130e+00	4.596e+07	1.073e+03	
2.350e+00	4.624e+07	1.073e+03	
2.530e+00	4.613e+07	1.073e+03	
2.700e+00	4.603e+07	1.073e+03	
2.930e+00	4.836e+07	1.073e+03	
3.180e+00	5.068e+07	1.073e+03	unload

0.000e+00	1.440e+07	1.073e+03	annealed
7.000e-02	1.598e+07	1.073e+03	
1.300e-01	1.717e+07	1.073e+03	
2.300e-01	1.916e+07	1.073e+03	
3.500e-01	2.073e+07	1.073e+03	
4.500e-01	2.150e+07	1.073e+03	
5.500e-01	2.267e+07	1.073e+03	
6.500e-01	2.343e+07	1.073e+03	
7.700e-01	2.418e+07	1.073e+03	
8.700e-01	2.495e+07	1.073e+03	
9.700e-01	2.489e+07	1.073e+03	
1.070e+00	2.564e+07	1.073e+03	
1.170e+00	2.600e+07	1.073e+03	
1.350e+00	2.671e+07	1.073e+03	
1.590e+00	2.780e+07	1.073e+03	

1.750e+00	2.853e+07	1.073e+03	
1.950e+00	2.965e+07	1.073e+03	
2.140e+00	3.035e+07	1.073e+03	
2.370e+00	3.145e+07	1.073e+03	
2.550e+00	3.217e+07	1.073e+03	
2.770e+00	3.368e+07	1.073e+03	
2.950e+00	3.439e+07	1.073e+03	
3.190e+00	3.507e+07	1.073e+03	
3.300e+00	3.582e+07	1.073e+03	unload
0.000e+00	1.726e+07	1.173e+03	as-grown
4.000e-02	1.928e+07	1.173e+03	
7.000e-02	2.131e+07	1.173e+03	
1.200e-01	2.333e+07	1.173e+03	
2.200e-01	2.656e+07	1.173e+03	
3.600e-01	2.894e+07	1.173e+03	
4.100e-01	3.056e+07	1.173e+03	
4.600e-01	3.053e+07	1.173e+03	
4.900e-01	3.091e+07	1.173e+03	
5.400e-01	3.048e+07	1.173e+03	
6.600e-01	2.795e+07	1.173e+03	
7.700e-01	2.460e+07	1.173e+03	
8.700e-01	2.289e+07	1.173e+03	
9.700e-01	2.160e+07	1.173e+03	
1.060e+00	2.031e+07	1.173e+03	
1.180e+00	2.024e+07	1.173e+03	
1.260e+00	2.019e+07	1.173e+03	
1.360e+00	2.055e+07	1.173e+03	
1.460e+00	2.172e+07	1.173e+03	unload
0.000e+00	1.069e+07	1.273e+03	as-grown
3.000e-02	1.187e+07	1.173e+03	
8.000e-02	1.314e+07	1.173e+03	
1.300e-01	1.432e+07	1.173e+03	
2.000e-01	1.471e+07	1.173e+03	
2.600e-01	1.549e+07	1.173e+03	
3.600e-01	1.540e+07	1.173e+03	
4.600e-01	1.618e+07	1.173e+03	
5.600e-01	1.648e+07	1.173e+03	
6.600e-01	1.687e+07	1.173e+03	
7.800e-01	1.765e+07	1.173e+03	
8.600e-01	1.755e+07	1.173e+03	
9.600e-01	1.795e+07	1.173e+03	
1.060e+00	1.785e+07	1.173e+03	
1.180e+00	1.863e+07	1.173e+03	
1.280e+00	1.814e+07	1.173e+03	

1.410e+00	1.893e+07	1.173e+03	unload

Comments on Data

Data read from figure
CZ-crystals exhibit yield drop at 1073 K; magnitude of drop decreases progressively with increasing deformation temperature. The drop is absent at 1273 K.
At 1073 K, CZ-crystals exhibit a luders strain. This strain is absent at 1173 K and higher.

Reference

LUEDERS BANDS IN DEFORMED SILICON CRYSTALS.
Mahajan, S. Brasen, D. Haasen, P.
ACTA METALL.
27, 1165-73, 1979.

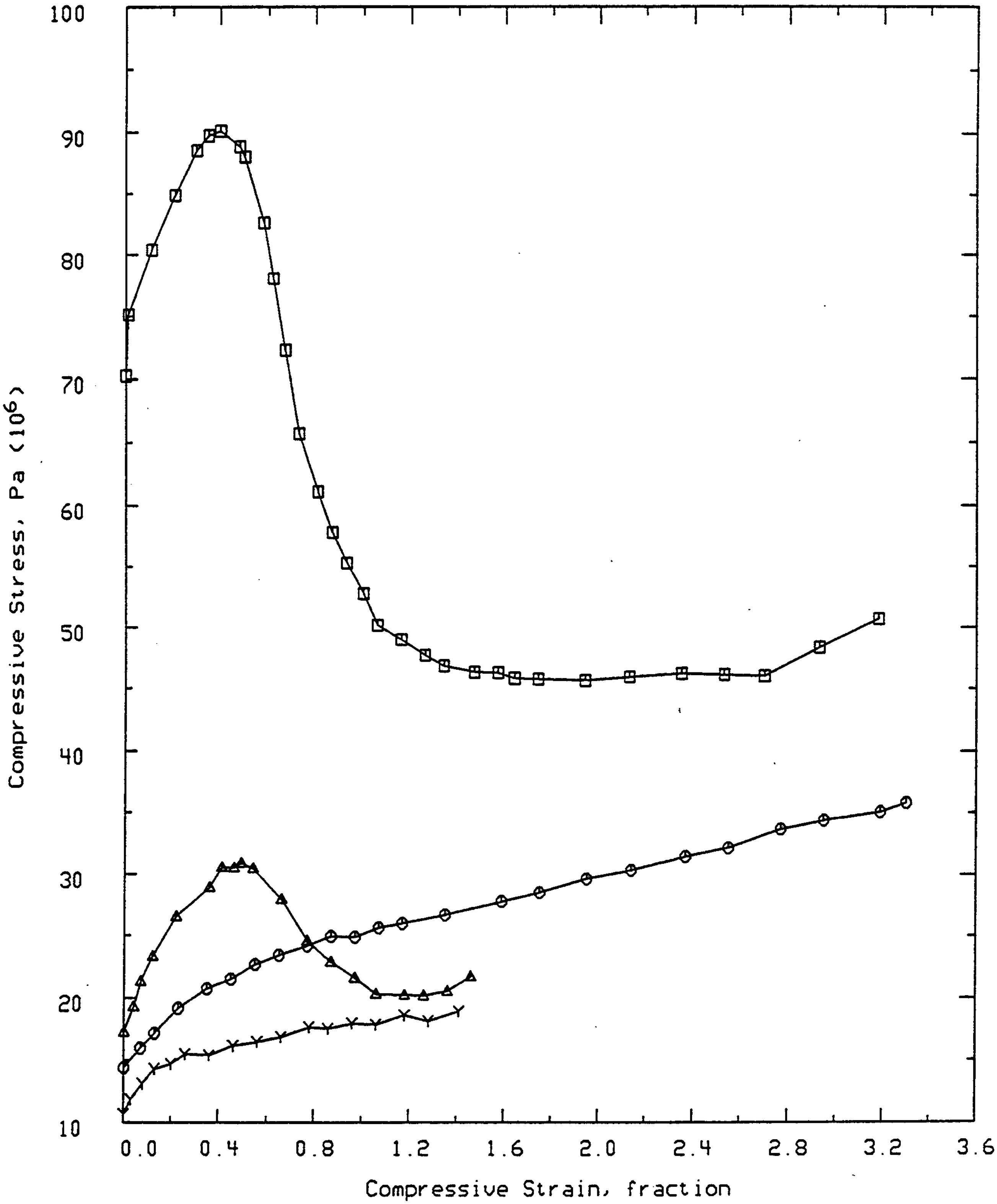

Figure 132 Compressive Stress of Silicon

MATERIAL: Silicon

PROPERTY: Compressive Stress

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DATA SET 133

****

Material Preparation

Crystal Growing Method :
Float-zone grown,dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Specimens ground and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	0.5	cm
Width	0.5	cm
Thickness	1.25	cm

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Test equipment not specified, probably Instron machine.
Tests done under forming gas (mixture of N(2) and H(2)).
Parameters-Codified :
Strain Rate : 6.7e-05 s[-1]

Measured/Evaluated Properties

X : Compressive Strain	%
Y : Compressive Stress	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1	Remarks:
0.000e+00	4.811e+07	1.073e+03	as-grown
4.000e-02	4.888e+07	1.073e+03	
1.100e-01	5.343e+07	1.073e+03	
2.100e-01	5.723e+07	1.073e+03	
2.800e-01	6.103e+07	1.073e+03	
3.600e-01	6.331e+07	1.073e+03	
4.200e-01	6.597e+07	1.073e+03	
5.100e-01	6.826e+07	1.073e+03	
6.200e-01	6.902e+07	1.073e+03	
6.800e-01	6.865e+07	1.073e+03	

7.400e-01	6.715e+07	1.073e+03	
8.500e-01	6.450e+07	1.073e+03	
9.400e-01	6.148e+07	1.073e+03	
1.020e+00	5.769e+07	1.073e+03	
1.100e+00	5.467e+07	1.073e+03	
1.190e+00	5.203e+07	1.073e+03	
1.240e+00	5.014e+07	1.073e+03	
1.320e+00	4.863e+07	1.073e+03	
1.420e+00	4.713e+07	1.073e+03	
1.550e+00	4.562e+07	1.073e+03	
1.700e+00	4.337e+07	1.073e+03	
1.840e+00	4.262e+07	1.073e+03	
1.960e+00	4.112e+07	1.073e+03	
2.090e+00	3.999e+07	1.073e+03	
2.220e+00	3.926e+07	1.073e+03	
2.360e+00	3.813e+07	1.073e+03	
2.500e+00	3.777e+07	1.073e+03	
2.640e+00	3.702e+07	1.073e+03	
2.720e+00	3.703e+07	1.073e+03	
2.810e+00	3.666e+07	1.073e+03	
2.930e+00	3.743e+07	1.073e+03	
3.020e+00	3.782e+07	1.073e+03	
3.240e+00	3.898e+07	1.073e+03	unload
0.000e+00	1.438e+07	1.173e+03	as-grown
1.000e-01	1.704e+07	1.173e+03	
1.800e-01	1.933e+07	1.173e+03	
2.900e-01	2.086e+07	1.173e+03	
4.000e-01	2.201e+07	1.173e+03	
4.900e-01	2.277e+07	1.173e+03	
5.000e-01	2.278e+07	1.173e+03	
7.000e-01	2.128e+07	1.173e+03	
8.700e-01	1.940e+07	1.173e+03	
1.010e+00	1.714e+07	1.173e+03	
1.110e+00	1.526e+07	1.173e+03	
1.210e+00	1.413e+07	1.173e+03	
1.310e+00	1.376e+07	1.173e+03	
1.410e+00	1.340e+07	1.173e+03	
1.490e+00	1.341e+07	1.173e+03	
1.610e+00	1.417e+07	1.173e+03	
1.750e+00	1.495e+07	1.173e+03	
1.810e+00	1.533e+07	1.173e+03	
1.920e+00	1.648e+07	1.173e+03	
2.090e+00	1.726e+07	1.173e+03	
2.210e+00	1.802e+07	1.173e+03	
2.400e+00	1.881e+07	1.173e+03	

2.630e+00	1.921e+07	1.173e+03	
2.800e+00	1.923e+07	1.173e+03	unload
0.000e+00	6.430e+06	1.273e+03	as-grown
3.000e-02	7.940e+06	1.273e+03	
1.100e-01	7.950e+06	1.273e+03	
2.000e-01	8.720e+06	1.273e+03	
2.600e-01	8.340e+06	1.273e+03	
3.700e-01	8.360e+06	1.273e+03	
4.300e-01	7.600e+06	1.273e+03	
5.200e-01	7.610e+06	1.273e+03	
5.800e-01	7.240e+06	1.273e+03	
7.100e-01	7.260e+06	1.273e+03	
8.600e-01	7.270e+06	1.273e+03	
1.010e+00	7.670e+06	1.273e+03	
1.210e+00	8.450e+06	1.273e+03	
1.400e+00	8.840e+06	1.273e+03	
1.610e+00	9.630e+06	1.273e+03	
1.810e+00	9.650e+06	1.273e+03	
2.000e+00	1.042e+07	1.273e+03	
2.210e+00	1.121e+07	1.273e+03	
2.510e+00	1.124e+07	1.273e+03	unload

Comments on Data

Data read from figure
FZ-crystal exhibit yield drop at 1073 K; magnitude of drop decreases progressively with increasing deformation temperature.
The drop is absent at 1273 K.
The luders strain at 1073 K is not very well defined as was the case for CZ-crystal.

Reference

LUEDERS BANDS IN DEFORMED SILICON CRYSTALS.
Mahajan, S.   Brasen, D.   Haasen, P.
ACTA METALL.
27, 1165-73, 1979.

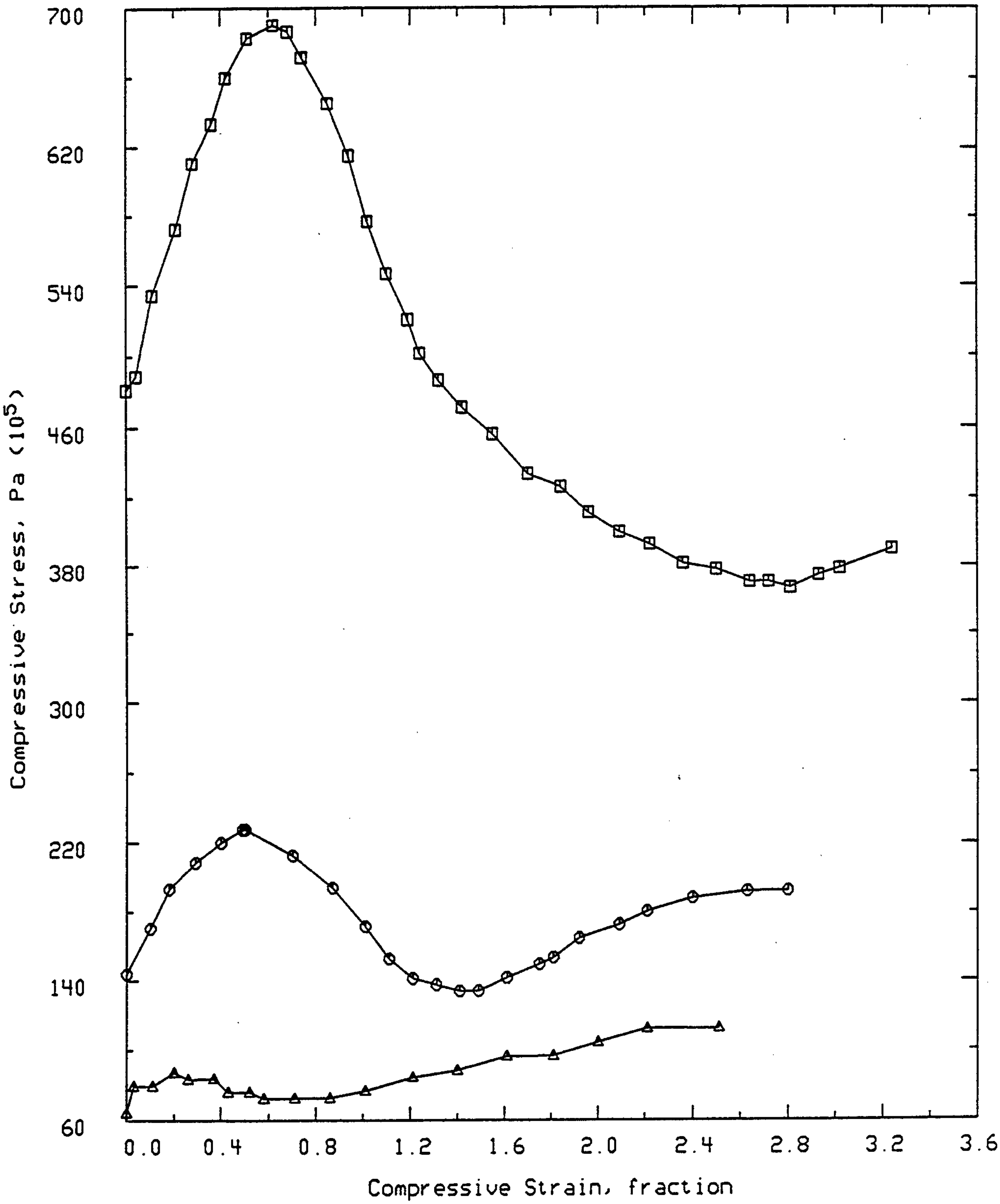

Figure 133 Compressive Stress of Silicon

MATERIAL: Silicon

PROPERTY: Compressive Stress

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 134

****

Vendor/Producer/Fabricator

POLYROD-grade polycrystals obtained from WACKER.

Conditioning History Of Alloys

Heat-Treatment Sequence : Tested in the as-received form

Material Preparation

Film Deposition Method :

Very-high purity polycrystals, POLYROD grade obtained by Vapor deposition (CVD) on a single crystal core and grown to a diameter of about 100 mm. Crystals exhibit a pronounced [110] texture along the radial growth orientation

Specimen Identification

Dimensions (Geometry) :

Length	12.	mm
Width	4.	mm
Thickness	4.	mm

Additional Identifiers :

Samples stressed perpendicular to growth axis

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method

High-temperature apparatus mounted to Instron machine. Tests done under reformed gas.

Parameters-Codified :

Strain Rate : 7.0e-06 s[-1]

Measured/Evaluated Properties

X : Compressive Strain	%
Y : Compressive Stress	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
0.000e+00	0.000e+00	1.623e+03
1.800e-01	1.590e+07	1.623e+03
4.900e-01	2.810e+07	1.623e+03
7.900e-01	3.300e+07	1.623e+03

2.020e+00	3.670e+07	1.623e+03
3.060e+00	3.680e+07	1.623e+03
4.050e+00	3.920e+07	1.623e+03
5.210e+00	3.930e+07	1.623e+03
5.460e+00	4.060e+07	1.623e+03
5.950e+00	4.060e+07	1.623e+03
6.620e+00	4.060e+07	1.623e+03
0.000e+00	4.900e+06	1.523e+03
6.100e-01	2.080e+07	1.523e+03
8.600e-01	3.300e+07	1.523e+03
1.100e+00	4.160e+07	1.523e+03
1.400e+00	4.650e+07	1.523e+03
1.710e+00	4.890e+07	1.523e+03
2.690e+00	5.140e+07	1.523e+03
3.740e+00	5.270e+07	1.523e+03
4.350e+00	5.390e+07	1.523e+03
0.000e+00	0.000e+00	1.423e+03
2.400e-01	1.710e+07	1.423e+03
7.300e-01	4.280e+07	1.423e+03
1.220e+00	6.110e+07	1.423e+03
1.590e+00	8.070e+07	1.423e+03
1.770e+00	8.680e+07	1.423e+03
2.080e+00	9.170e+07	1.423e+03
2.570e+00	9.420e+07	1.423e+03
3.360e+00	9.660e+07	1.423e+03
4.040e+00	9.790e+07	1.423e+03
0.000e+00	0.000e+00	1.323e+03
5.400e-01	8.550e+07	1.323e+03
6.600e-01	1.063e+08	1.323e+03
7.800e-01	1.234e+08	1.323e+03
1.150e+00	1.368e+08	1.323e+03
1.460e+00	1.430e+08	1.323e+03
2.010e+00	1.467e+08	1.323e+03
2.680e+00	1.503e+08	1.323e+03
4.090e+00	1.516e+08	1.323e+03
5.810e+00	1.517e+08	1.323e+03
6.670e+00	1.517e+08	1.323e+03
7.650e+00	1.494e+08	1.323e+03
8.570e+00	1.469e+08	1.323e+03
9.310e+00	1.433e+08	1.323e+03
9.920e+00	1.372e+08	1.323e+03

Comments on Data

Data was digitized from Figure 2.
These stress-strain curves of as-grown samples are characterized by high yield stresses, still approximately 40 MPa at 0.9 melting temperature and small hardening rate, becoming negative at 1323 K, strain > 5.0e-02. Samples cut parallel to the radial growth direction are harder than samples cut parallel to the rod axis and have a smaller range of microplasticity.

Reference

MECHANICAL BEHAVIOR OF POLYCRYSTALS AND SINGLE CRYSTALS OF SILICON.
Omri, M. Michel, J. P. Tete, C.
George, A.
STRENGTH OF METALS AND ALLOYS, VOL. 1, PROC. INT. CONF., ICSMA 7, 1985
1, 75-80, 1986.
(Edited by H. J. McQueen, J. P. Bailon,
J. I. Dickson, J. J. Jonas and M. G. Akben; Pergamon
Press: Elmsford, New York)

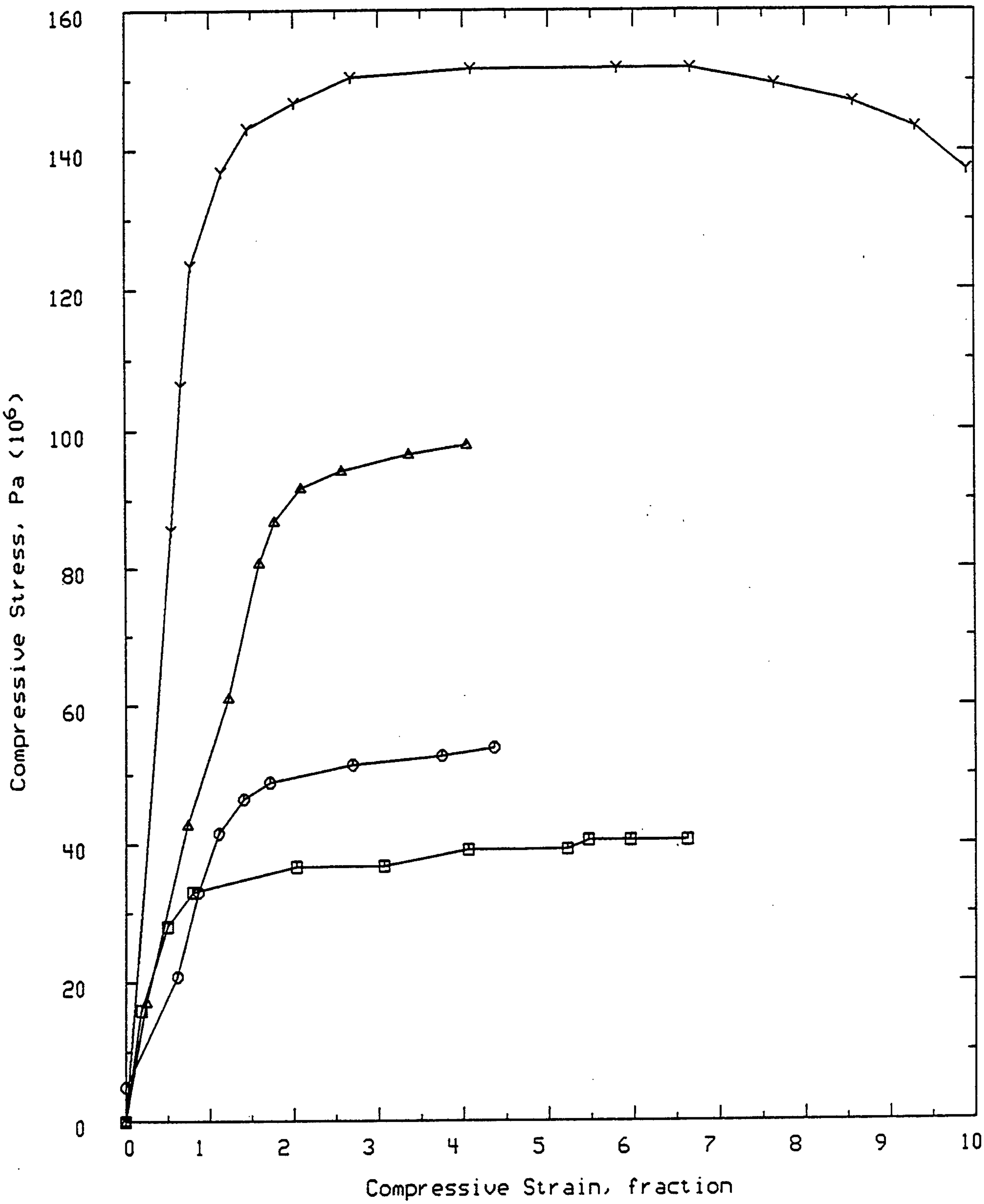

Figure 134 Compressive Stress of Silicon

MATERIAL: Silicon

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 135

PROPERTY: Compressive Stress

****

Vendor/Producer/Fabricator

POLYROD-grade polycrystals obtained from WACKER.

Conditioning History Of Alloys

Heat-Treatment Sequence : Tested in the as-received form

Material Preparation

Film Deposition Method :

Very-high purity polycrystals, POLYROD grade obtained by Vapor deposition (CVD) on a single crystal core and grown to a diameter of about 100 mm. Crystals exhibit a pronounced [110] texture along the radial growth orientation

Specimen Identification

Dimensions (Geometry) :

Length	12.	mm
Width	4.	mm
Thickness	4.	mm

Additional Identifiers :

Sampels stressed along growth axis

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
High-temperature apparatus mounted to Instron machine.
Tests done under reformed gas.

Parameters-Codified :

Strain Rate : 7.0e-06 s[-1]

Measured/Evaluated Properties

X : Compressive Strain	%
Y : Compressive Stress	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
0.000e+00	0.000e+00	1.623e+03
6.000e-02	2.320e+07	1.623e+03
4.300e-01	3.790e+07	1.623e+03
6.700e-01	4.280e+07	1.623e+03

1.160e+00	4.400e+07	1.623e+03
2.020e+00	4.530e+07	1.623e+03
3.060e+00	4.530e+07	1.623e+03
4.170e+00	4.660e+07	1.623e+03
4.900e+00	4.660e+07	1.623e+03
5.700e+00	4.790e+07	1.623e+03
6.360e+00	4.550e+07	1.623e+03
6.870e+00	4.550e+07	1.623e+03
8.220e+00	4.430e+07	1.623e+03
0.000e+00	0.000e+00	1.523e+03
1.200e-01	3.050e+07	1.523e+03
2.400e-01	4.150e+07	1.523e+03
4.800e-01	5.620e+07	1.523e+03
6.000e-01	6.230e+07	1.523e+03
9.100e-01	6.600e+07	1.523e+03
1.100e+00	6.850e+07	1.523e+03
2.500e+00	7.100e+07	1.523e+03
3.610e+00	7.100e+07	1.523e+03
4.590e+00	7.110e+07	1.523e+03
5.580e+00	7.110e+07	1.523e+03
0.000e+00	0.000e+00	1.423e+03
1.800e-01	4.150e+07	1.423e+03
3.600e-01	6.480e+07	1.423e+03
4.800e-01	8.060e+07	1.423e+03
7.300e-01	9.530e+07	1.423e+03
9.700e-01	1.039e+08	1.423e+03
1.460e+00	1.063e+08	1.423e+03
1.770e+00	1.076e+08	1.423e+03
3.110e+00	1.088e+08	1.423e+03
4.650e+00	1.101e+08	1.423e+03
5.940e+00	1.090e+08	1.423e+03
7.100e+00	1.078e+08	1.423e+03
0.000e+00	0.000e+00	1.323e+03
2.400e-01	4.150e+07	1.323e+03
4.200e-01	8.060e+07	1.323e+03
6.600e-01	1.075e+08	1.323e+03
7.800e-01	1.222e+08	1.323e+03
1.030e+00	1.442e+08	1.323e+03
1.350e+00	1.515e+08	1.323e+03
1.760e+00	1.564e+08	1.323e+03
2.000e+00	1.576e+08	1.323e+03
2.800e+00	1.601e+08	1.323e+03
3.720e+00	1.602e+08	1.323e+03

4.400e+00	1.602e+08	1.323e+03
5.260e+00	1.590e+08	1.323e+03
6.240e+00	1.566e+08	1.323e+03
6.920e+00	1.542e+08	1.323e+03
8.020e+00	1.506e+08	1.323e+03
9.000e+00	1.457e+08	1.323e+03
9.980e+00	1.397e+08	1.323e+03
1.097e+01	1.324e+08	1.323e+03
1.201e+01	1.251e+08	1.323e+03

Comments on Data

Data was digitized from Figure 2.
These stress-strain curves of as-grown samples are characterized by high yield stresses, still approximately 40 MPa at 0.9 melting temperature and small hardening rate, becoming negative at 1323 K, strain > 5.0e-02. Samples cut parallel to the radial growth direction are harder than samples cut parallel to the rod axis and have a smaller range of microplasticity.

Reference

MECHANICAL BEHAVIOR OF POLYCRYSTALS AND SINGLE CRYSTALS OF SILICON.
Omri, M. Michel, J. P. Tete, C.
George, A.
STRENGTH OF METALS AND ALLOYS, VOL. 1, PROC. INT. CONF., ICSMA 7, 1985
1, 75-80, 1986.
(Edited by H. J. McQueen, J. P. Bailon,
J. I. Dickson, J. J. Jonas and M. G. Akben; Pergamon
Press: Elmsford, New York)

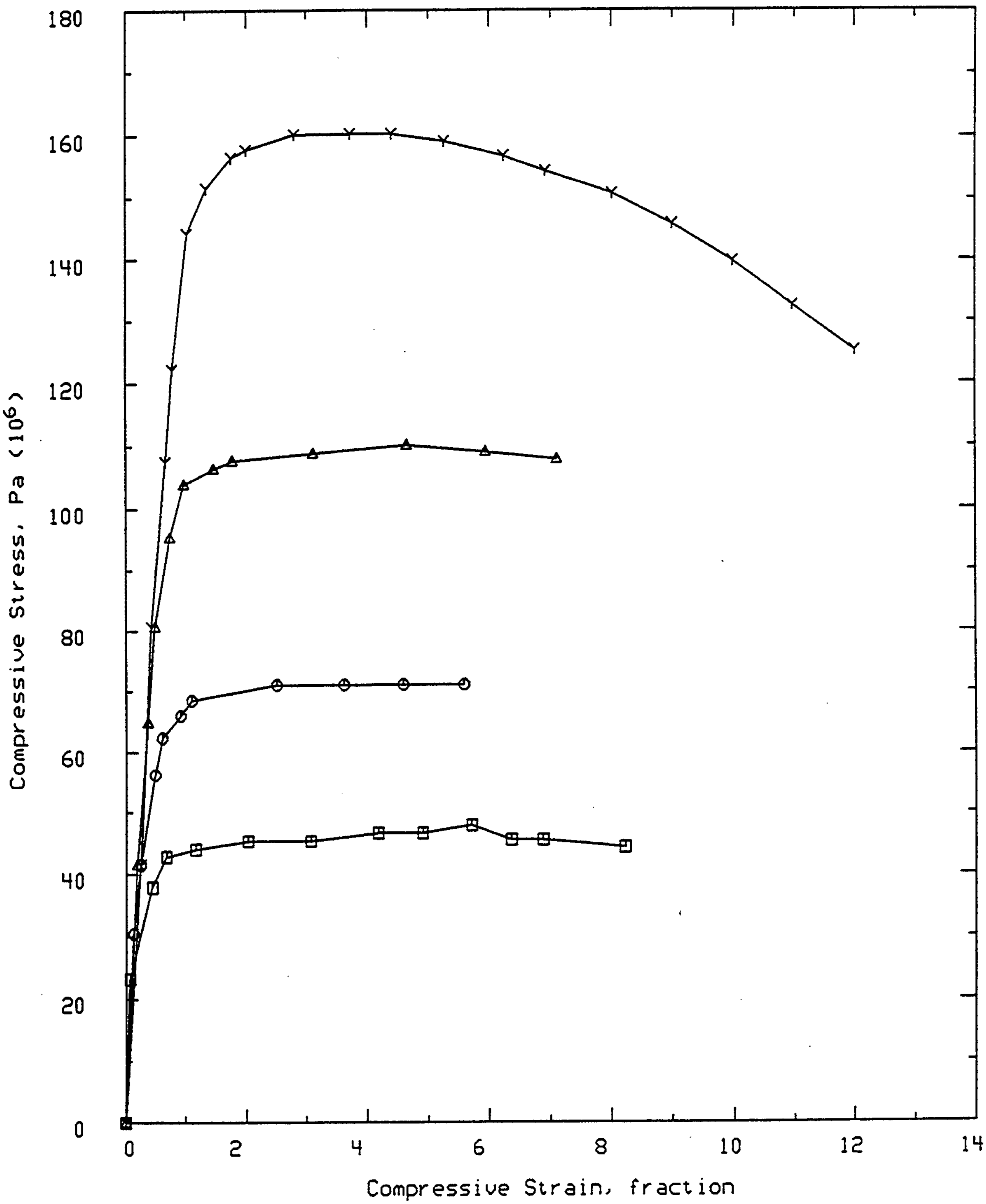

Figure 135 Compressive Stress of Silicon

MATERIAL: Silicon

PROPERTY: Compressive Stress

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 136

****

Vendor/Producer/Fabricator

POLYROD-grade polycrystals obtained from WACKER.

Conditioning History Of Alloys

Heat-Treatment Sequence : Annealed at 1653 K for 24 hrs.

Material Preparation

Film Deposition Method :

Very-high purity polycrystals, POLYROD grade obtained by Vapor deposition (CVD) on a single crystal core and grown to a diameter of about 100 mm. Crystals exhibit a pronounced [110] texture along the radial growth orientation

Specimen Identification

Dimensions (Geometry) :

Length	12.	mm
Width	4.	mm
Thickness	4.	mm

Additional Identifiers :

Samples stressed perpendicular to growth axis.

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method

High-temperature apparatus mounted to Instron machine.

Tests done under reformed gas.

Parameters-Codified :

Strain Rate : 7.0e-06 s[-1]

Measured/Evaluated Properties

X	: Compressive Strain	%
Y	: Compressive Stress	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
0.000e+00	8.610e+06	1.323e+03
5.500e-01	4.040e+07	1.323e+03
8.000e-01	5.270e+07	1.323e+03
1.300e+00	6.490e+07	1.323e+03

2.290e+00	7.720e+07	1.323e+03
3.410e+00	8.700e+07	1.323e+03
4.650e+00	9.200e+07	1.323e+03
6.200e+00	9.810e+07	1.323e+03
7.570e+00	1.019e+08	1.323e+03
8.380e+00	1.043e+08	1.323e+03
9.500e+00	1.056e+08	1.323e+03
1.092e+01	1.068e+08	1.323e+03
1.198e+01	1.093e+08	1.323e+03
0.000e+00	8.600e+06	1.423e+03
4.900e-01	3.920e+07	1.423e+03
1.050e+00	5.270e+07	1.423e+03
1.550e+00	5.640e+07	1.423e+03
2.290e+00	6.130e+07	1.423e+03
3.160e+00	6.500e+07	1.423e+03
4.160e+00	6.870e+07	1.423e+03
5.590e+00	7.120e+07	1.423e+03
7.010e+00	7.370e+07	1.423e+03
8.010e+00	7.370e+07	1.423e+03
8.750e+00	7.370e+07	1.423e+03
0.000e+00	8.600e+06	1.523e+03
2.500e-01	1.700e+07	1.523e+03
4.300e-01	3.190e+07	1.523e+03
1.050e+00	3.920e+07	1.523e+03
1.740e+00	4.410e+07	1.523e+03
2.920e+00	4.660e+07	1.523e+03
3.970e+00	5.030e+07	1.523e+03
5.090e+00	5.280e+07	1.523e+03
6.460e+00	5.280e+07	1.523e+03
7.820e+00	5.410e+07	1.523e+03
9.190e+00	5.540e+07	1.523e+03
0.000e+00	7.300e+06	1.623e+03
8.100e-01	2.570e+07	1.623e+03
1.180e+00	3.190e+07	1.623e+03
2.100e+00	3.560e+07	1.623e+03
3.970e+00	3.930e+07	1.623e+03
6.080e+00	4.180e+07	1.623e+03
7.570e+00	4.310e+07	1.623e+03
8.690e+00	4.430e+07	1.623e+03

Comments on Data

Data was digitized from Figure 3.
A marked softening is observed for both orientations. At

1623 K the flow stress is not modified for samples cut parallel to the rod axis but is reduced by 25 percent for samples cut parallel to the radial growth direction. Hardening rate after annealing is larger--decreased softening at large strains.

Reference

MECHANICAL BEHAVIOR OF POLYCRYSTALS AND SINGLE CRYSTALS OF SILICON.
Omri, M. Michel, J. P. Tete, C.
George, A.
STRENGTH OF METALS AND ALLOYS, VOL. 1, PROC. INT. CONF., ICSMA 7, 1985
1, 75-80, 1986.
(Edited by H. J. McQueen, J. P. Bailon,
J. I. Dickson, J. J. Jonas and M. G. Akben; Pergamon
Press: Elmsford, New York)

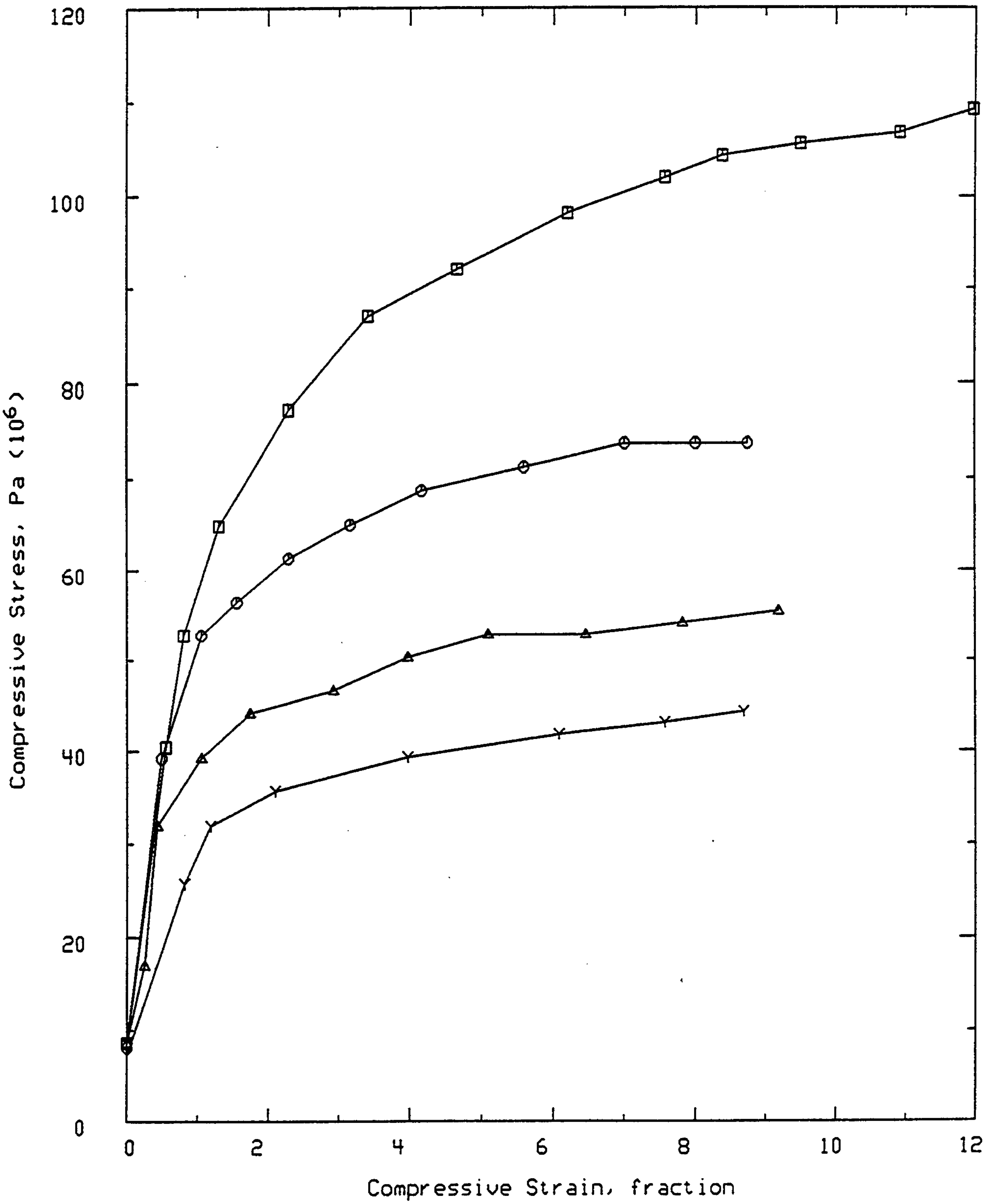

Figure 136 Compressive Stress of Silicon

MATERIAL: Silicon	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Compressive Stress	DATA SET 137

****

Vendor/Producer/Fabricator

POLYROD-grade polycrystals obtained from WACKER.

Conditioning History Of Alloys

Heat-Treatment Sequence : Annealed at 1653 K for 24 hrs.

Material Preparation

Film Deposition Method :

Very-high purity polycrystals, POLYROD grade obtained by
Vapor deposition (CVD) on a single crystal core and grown to
a diameter of about 100 mm. Crystals exhibit a pronounced [110]
texture along the radial growth orientation

Specimen Identification

Dimensions (Geometry) :

Length	12.	mm
Width	4.	mm
Thickness	4.	mm

Additional Identifiers :

Samples stressed along the growth axis.

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
High-temperature apparatus mounted to Instron machine.
Tests done under reformed gas.

Parameters-Codified :

Strain Rate : 7.0e-06 s[-1]

Measured/Evaluated Properties

X : Compressive Strain	%
Y : Compressive Stress	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
0.000e+00	8.600e+06	1.323e+03
0.000e+00	3.310e+07	1.323e+03
1.800e-01	4.040e+07	1.323e+03
3.700e-01	5.140e+07	1.323e+03

6.800e-01	5.880e+07	1.323e+03
8.000e-01	6.490e+07	1.323e+03
1.420e+00	7.470e+07	1.323e+03
2.540e+00	8.330e+07	1.323e+03
4.340e+00	9.320e+07	1.323e+03
5.710e+00	9.810e+07	1.323e+03
6.940e+00	1.018e+08	1.323e+03
8.630e+00	1.068e+08	1.323e+03
1.018e+01	1.105e+08	1.323e+03
0.000e+00	8.600e+06	1.423e+03
0.000e+00	3.060e+07	1.423e+03
1.200e-01	4.040e+07	1.423e+03
3.100e-01	5.270e+07	1.423e+03
7.400e-01	5.760e+07	1.423e+03
1.300e+00	6.250e+07	1.423e+03
2.420e+00	6.990e+07	1.423e+03
3.910e+00	7.480e+07	1.423e+03
5.210e+00	7.850e+07	1.423e+03
6.640e+00	8.220e+07	1.423e+03
7.880e+00	8.470e+07	1.423e+03
8.880e+00	8.600e+07	1.423e+03
9.370e+00	8.600e+07	1.423e+03
9.680e+00	8.720e+07	1.423e+03
0.000e+00	8.600e+06	1.523e+03
3.700e-01	2.450e+07	1.523e+03
7.400e-01	4.170e+07	1.523e+03
9.300e-01	4.530e+07	1.523e+03
1.180e+00	4.780e+07	1.523e+03
1.670e+00	5.030e+07	1.523e+03
2.290e+00	5.390e+07	1.523e+03
3.160e+00	5.520e+07	1.523e+03
4.030e+00	5.770e+07	1.523e+03
5.280e+00	6.020e+07	1.523e+03
6.700e+00	6.260e+07	1.523e+03
7.700e+00	6.270e+07	1.523e+03
8.570e+00	6.390e+07	1.523e+03
0.000e+00	1.710e+07	1.623e+03
3.700e-01	2.700e+07	1.623e+03
1.050e+00	3.190e+07	1.623e+03
2.170e+00	3.440e+07	1.623e+03
3.970e+00	3.810e+07	1.623e+03
4.970e+00	4.060e+07	1.623e+03
6.150e+00	4.180e+07	1.623e+03

7.570e+00	4.430e+07	1.623e+03
8.630e+00	4.430e+07	1.623e+03

Comments on Data

Data was digitized from Figure 3.
A marked softening is observed for both orientations. At 1623 K the flow stress is not modified for samples cut parallel to the rod axis but is reduced by 25 percent for samples cut parallel to the radial growth direction. Hardening rate after annealing is larger--decreased softening at large strains.

Reference

MECHANICAL BEHAVIOR OF POLYCRYSTALS AND SINGLE CRYSTALS OF SILICON.
Omri, M. Michel, J. P. Tete, C.
George, A.
STRENGTH OF METALS AND ALLOYS, VOL. 1, PROC. INT. CONF., ICSMA 7, 1985
1, 75-80, 1986.
(Edited by H. J. McQueen, J. P. Bailon,
J. I. Dickson, J. J. Jonas and M. G. Akben; Pergamon
Press: Elmsford, New York)

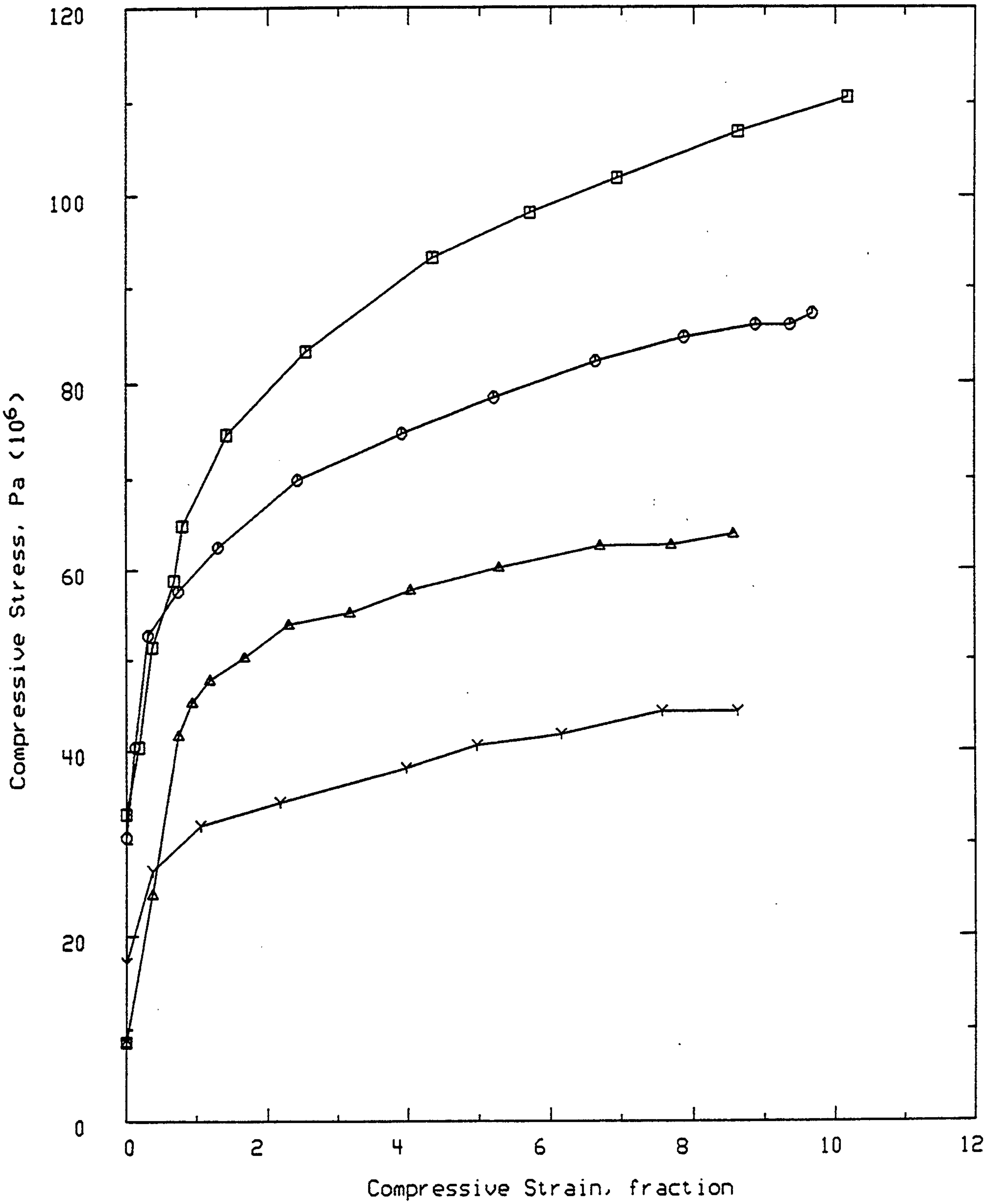

Figure 137 Compressive Stress of Silicon

MATERIAL: Silicon: B doped

PROPERTY: Compressive Strength, Lower Yield

****

Composition

1.e18	cm^{-3}	Boron Dopant Concentration

Material Preparation

Crystal Growing Method :

Float-zone grown, dislocation free, p-type, boron doped

Descriptors-Textual :

Crystals cut with a diamond saw and mechanically polished with diamond paste (grade 1 micron)

Specimen Identification

Dimensions (Geometry) :

Length	8.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Lateral faces were of {111} and {541} types

Additional Properties

Electrical Properties :

Electrical Resistivity	0.06	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Compression Tests of Pre-Strained Crystals
Specimens deformed under argon atmosphere in an Instron testing machine equipped with a high temperature furnace.

Parameters-Codified :

Pre-Strain Temperature : 1323. K
Pre-Strain Rate, Plastic : 2.e-05 s[-1] (pre-straining)

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Preconditioning Treatment

Descriptors-Textual :

Specimens pre-strained at 1323 K and 2.e-05 s[-1] strain rate; it was stopped at a permanent strain of 1.5 pct. and cooled under load.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Compressive Strength, Lower Yield	Pa
Z1	: Strain Rate	s^{-1}

Data Points :

X	Y	Z1
8.280e+02	7.720e+07	2.500e-06
8.600e+02	5.000e+07	2.500e-06
9.130e+02	2.570e+07	2.500e-06

Comments on Data

Data read from figure
Pre-deformation at higher temperatures allows plastic deformation to take place at lower temperatures without brittle fracture. Within the experimental uncertainty, the yield strength of the intrinsic and p-type silicon appear to be in good agreement.

Reference

ON THE PLASTICITY OF SILICON BELOW 650 DEGREES C.
Demenet, J. L. Desoyer, J. C.
Rabier, J. Veyssiere, P.
SCR. METALL.
18 (1), 41-5, 1984.

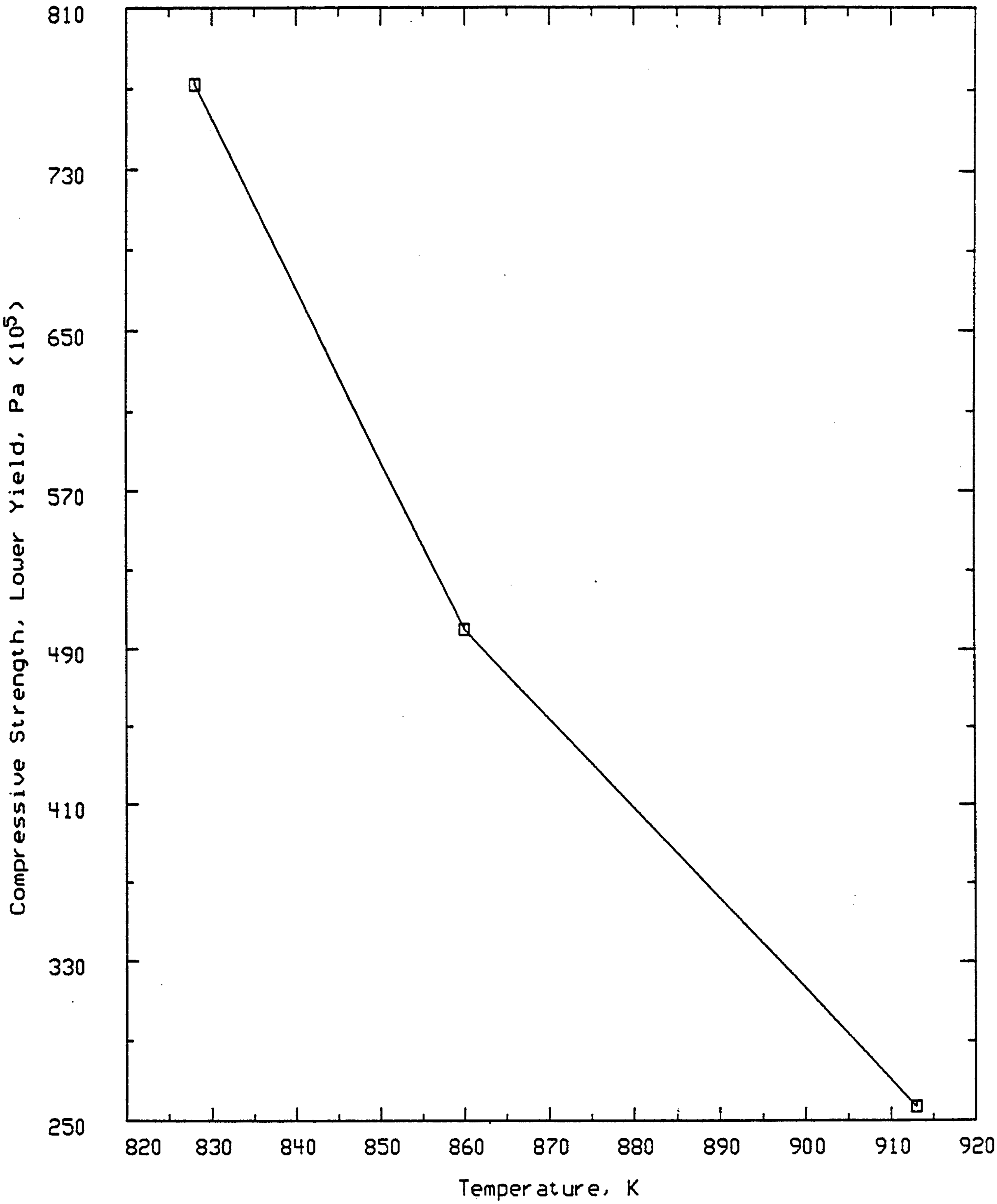

Figure 138 Compressive Strength, Lower Yield of Silicon: B doped

MATERIAL: Silicon: P doped

PROPERTY: Compressive Strength, Lower Yield

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DATA SET 139

****

Composition

9.e14 cm^{-3} Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :
Float-zone grown, dislocation-free, intrinsic
Descriptors-Textual :
Crystals cut with a diamond saw and mechanically polished with diamond paste (grade 1 micron)

Specimen Identification

Dimensions (Geometry) :

Length	8.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Lateral faces were of {111} and {541} types

Additional Properties

Electrical Properties :

Electrical Resistivity	5.0	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Tests of Pre-Strained Crystals.
Specimens deformed under argon atmosphere in an Instron testing machine equipped with a high temperature furnace.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Preconditioning Treatment
Descriptors-Textual :
Specimens pre-strained at 1323 K and 2.e-05 s[-1] strain rate; it was stopped at a permanent strain of 1.5 pct. and cooled under load.

Measurement/Evaluation Method

Parameters-Codified :
Pre-Strain Temperature : 1323. K
Pre-Strain Rate, Plastic : 2.e-05 s[-1] (pre-straining)

Measured/Evaluated Properties

X	: Temperature	K
Y	: Compressive Strength, Lower Yield	Pa
Z1	: Strain Rate	s^{-1}

Data Points :

X	Y	Z1
7.460e+02	3.030e+08	2.500e-06
7.710e+02	2.330e+08	2.500e-06
8.210e+02	9.700e+07	2.500e-06

Comments on Data

Data read from Figure 1.
Pre-deformation at higher temperatures allows plastic deformation to take place at lower temperatures without brittle fracture. Within the experimental uncertainty, the yield strength of the intrinsic and p-type silicon appear to be in good agreement.

Reference

ON THE PLASTICITY OF SILICON BELOW 650 DEGREES C.
Demenet, J. L. Desoyer, J. C.
Rabier, J. Veyssiere, P.
SCR. METALL.
18 (1), 41-5, 1984.

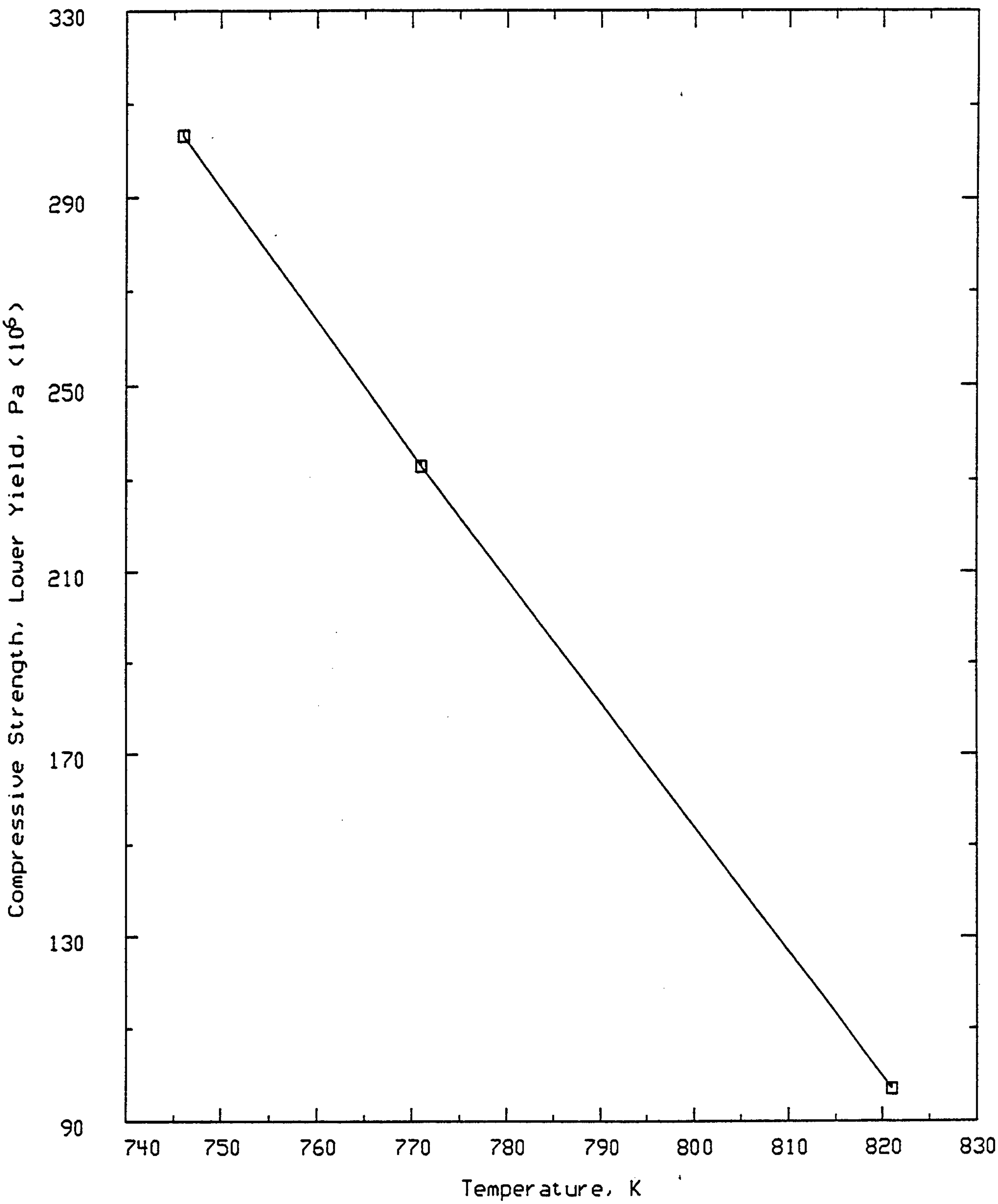

Figure 139 Compressive Strength, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Compressive Strength, Lower Yield

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DATA SET 140

****

Composition

6.e18	cm^{-3}	Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :
Float-zone grown, dislocation-free, n-type
Descriptors-Textual :
Crystals cut with a diamond saw and mechanically polished with diamond paste (grade 1 micron)

Specimen Identification

Dimensions (Geometry) :

Length	8.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Lateral faces were of {111} and {541} types

Additional Properties

Electrical Properties :

Electrical Resistivity	9.e-03	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded, Pre-Strained Bar Method
Specimens deformed under argon atmosphere in an Instron testing machine equipped with a high temperature furnace.
Parameters-Codified :
Pre-Strain Temperature : 948.-1323 K
Pre-Strain Rate, Plastic : 2.e-05 - 2.e-06 s[-1]

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Preconditioning Treatment
Descriptors-Textual :
Specimens pre-strained at different temperatures and strain rates and cooled under load.

Measured/Evaluated Properties

X : Temperature K

Y : Compressive Strength, Lower Yield — Pa
Z1 : Strain Rate — s^{-1}
Z2 : Pre-Strain Temperature — K
Z3 : Pre-Strain Rate, Plastic — s^{-1}

Data Points :

X	Y	Z1	Z2	Z3
6.690e+02	2.254e+08	2.500e-06	9.480e+02	2.000e-06
7.700e+02	6.750e+07	2.500e-06	9.480e+02	2.000e-06
6.580e+02	2.444e+08	2.500e-06	1.073e+03	2.000e-06
6.720e+02	2.165e+08	2.500e-06	1.073e+03	2.000e-06
6.870e+02	1.668e+08	2.500e-06	1.073e+03	2.000e-06
7.020e+02	1.420e+08	2.500e-06	1.073e+03	2.000e-06
7.220e+02	1.030e+08	2.500e-06	1.073e+03	2.000e-06
7.310e+02	9.300e+07	2.500e-06	1.073e+03	2.000e-06
7.660e+02	7.910e+07	2.500e-06	1.073e+03	2.000e-06
7.840e+02	5.860e+07	2.500e-06	1.073e+03	2.000e-06
8.070e+02	5.090e+07	2.500e-06	1.073e+03	2.000e-06
6.700e+02	1.774e+08	2.500e-06	1.323e+03	2.000e-05
6.860e+02	1.510e+08	2.500e-06	1.323e+03	2.000e-05
7.140e+02	1.160e+08	2.500e-06	1.323e+03	2.000e-05
7.370e+02	8.430e+07	2.500e-06	1.323e+03	2.000e-05
7.520e+02	7.470e+07	2.500e-06	1.323e+03	2.000e-05
7.690e+02	6.000e+07	2.500e-06	1.323e+03	2.000e-05
8.180e+02	3.770e+07	2.500e-06	1.323e+03	2.000e-05

Comments on Data

Data read from figure
Pre-straining at different temperatures and strain rates did not seem to have any appreciable effect on the yield strength. a very strong difference in yield strengths between n-type and intrinsic silicon is observed. The presence of phosphorus in the n-type lowers the yield strength by a ratio of 3 to 4 as compared to the intrinsic type.

Reference

ON THE PLASTICITY OF SILICON BELOW 650 DEGREES C.
Demenet, J. L. Desoyer, J. C.
Rabier, J. Veyssiere, P.
SCR. METALL.
18 (1), 41-5, 1984.

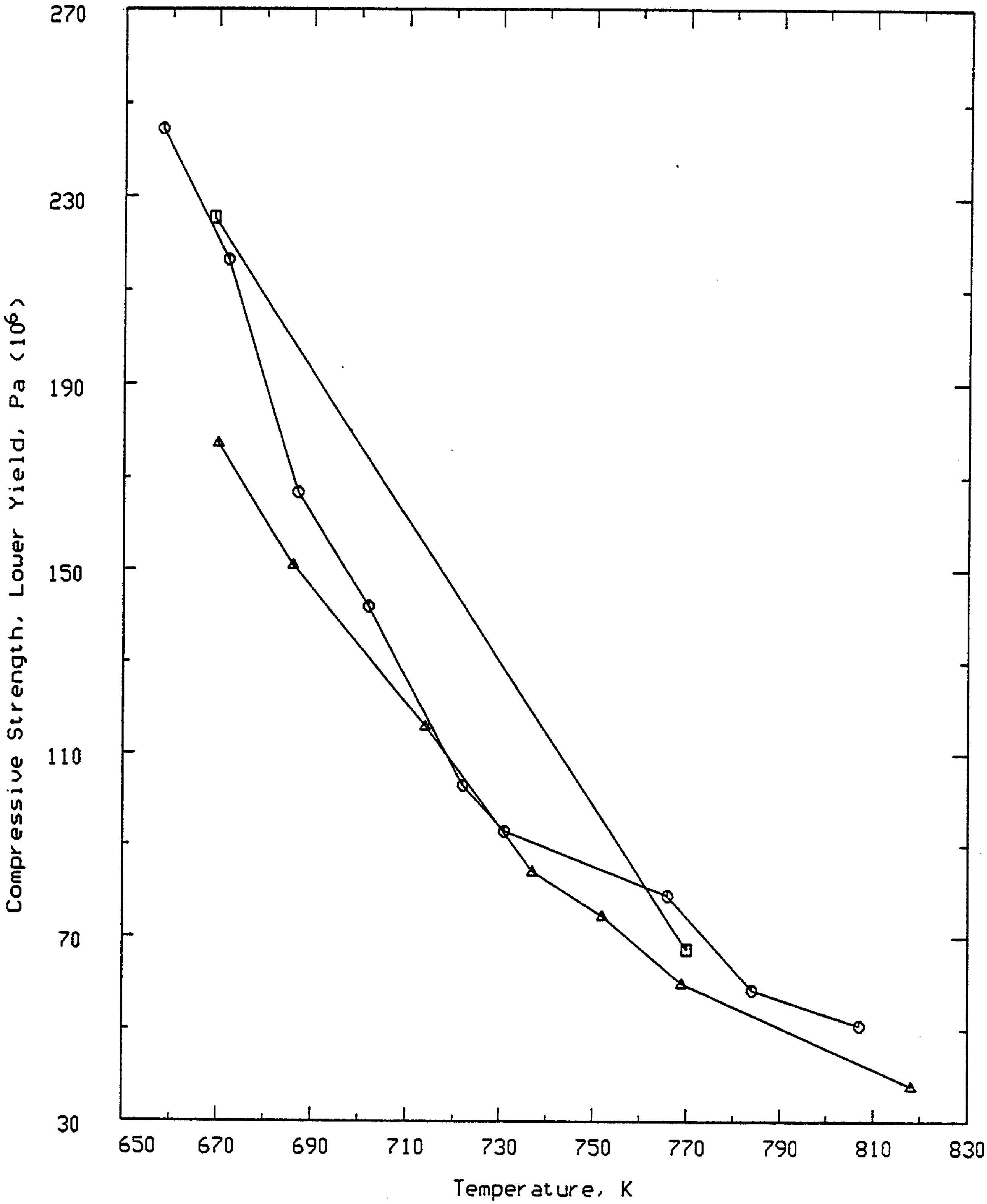

Figure 140 Compressive Strength, Lower Yield of Silicon, n-type

MATERIAL: Silicon: As doped

PROPERTY: Compressive Strength, Upper Yield

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DATA SET 141

****

Material Preparation

Crystal Growing Method :

Czochralski method, dislocation-free.

Additional Preparation/Conditioning

Surface Treatment :

Samples polished mechanically and chemically.

Specimen Identification

Dimensions (Geometry) :

Thickness	2.2	mm
Width	2.2	mm
Length	4.5	mm

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Compression test along <111> direction using a relaxometer.
Test done in an atmosphere of spectroscopically pure helium
Accuracy of the yield point measurements was +/- 3 pct.

Parameters-Codified :

Strain Rate : 6.8e-04 s[-1]

Measured/Evaluated Properties

X : Dopant Concentration	m^{-3}
Y : Compressive Strength, Upper Yield	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
2.199e+21	1.958e+08	1.073e+03
1.489e+22	1.957e+08	1.073e+03
1.339e+23	1.957e+08	1.073e+03
5.144e+23	1.933e+08	1.073e+03
2.622e+24	1.836e+08	1.073e+03
8.731e+24	1.666e+08	1.073e+03
2.707e+25	1.437e+08	1.073e+03
7.819e+25	1.207e+08	1.073e+03
1.282e+26	1.026e+08	1.073e+03

Comments on Data

As-doping lowers the upper and lower yield points of silicon.
Dopant concentration determined by Hall effect measuremment.

Reference

SOME MECHANICAL PROPERTIES OF STRONGLY DOPED SILICON SINGLE CRYSTALS.
Mil'vidskii, M. G. Stolyarov, O. G.
Berkova, A. V.
FIZ. TVERD. TELA (LENINGRAD)
6 (10), 3170-2, 1964.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE,
6 (10), 2531-2, 1965)

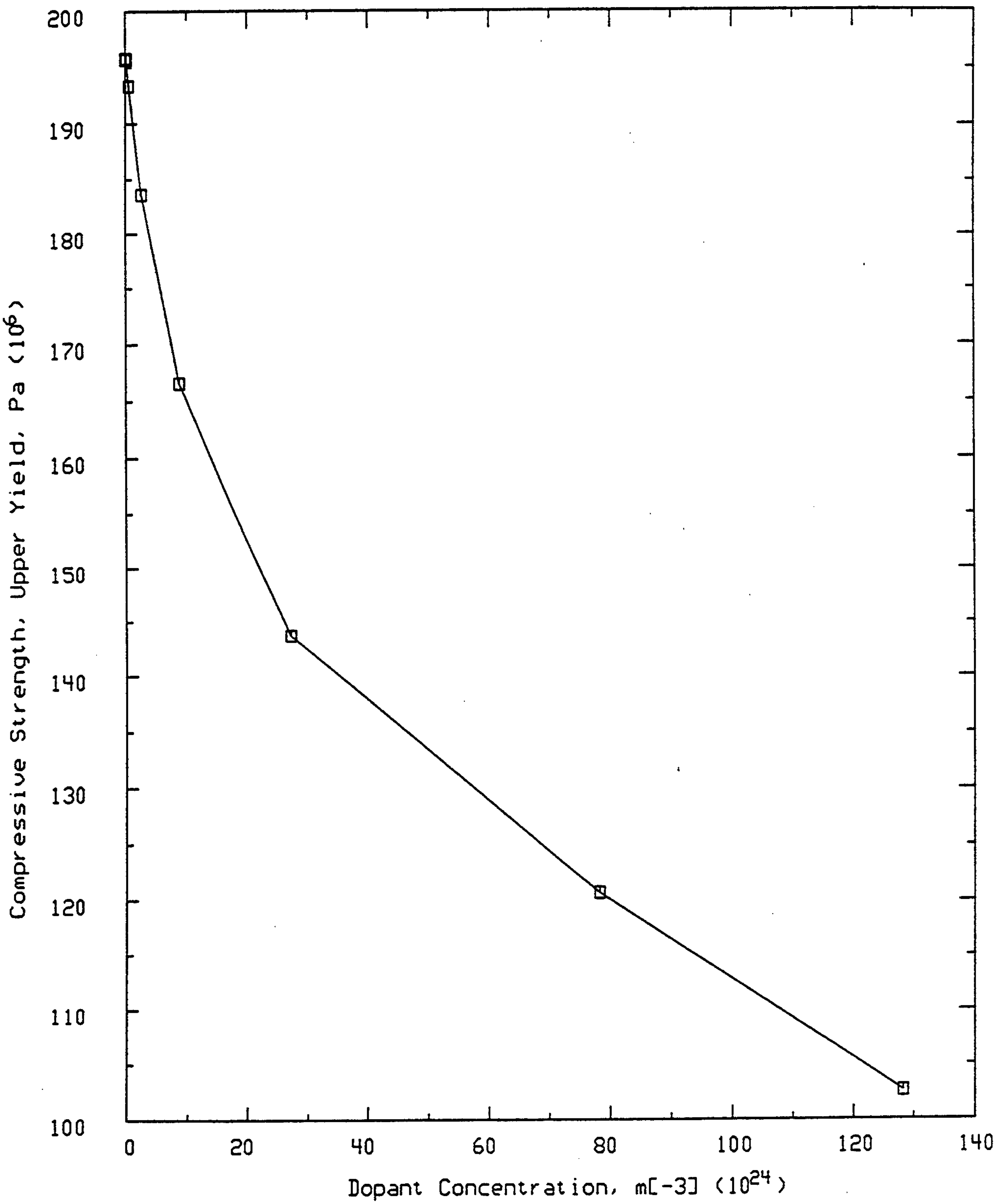

Figure 141 Compressive Strength, Upper Yield of Silicon: As doped

MATERIAL: Silicon: B doped

PROPERTY: Compressive Strength, Upper Yield

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DATA SET 142

****

Material Preparation

Crystal Growing Method :
Czochralski method, dislocation-free.

Additional Preparation/Conditioning

Surface Treatment :
Samples polished mechanically and chemically.

Specimen Identification

Dimensions (Geometry) :

Thickness	2.2	mm
Width	2.2	mm
Length	4.5	mm

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Compression test along <111> direction using a relaxometer.
Test done in an atmosphere of spectroscopically pure helium
Accuracy of the yield point measurements was +/- 3 pct.
Parameters-Codified :
Strain Rate : 6.8e-04 s[-1]

Measured/Evaluated Properties

X	: Dopant Concentration	m^{-3}
Y	: Compressive Strength, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
6.882e+24	2.276e+08	1.073e+03
1.964e+24	2.439e+08	1.073e+03
6.487e+23	2.461e+08	1.073e+03
2.545e+23	2.457e+08	1.073e+03

Comments on Data

B-doping increases the yield point of silicon.
Dopant concentration determined by Hall effect measuremment.

Reference

SOME MECHANICAL PROPERTIES OF STRONGLY DOPED SILICON SINGLE CRYSTALS.
Mil'vidskii, M. G. Stolyarov, O. G.
Berkova, A. V.
FIZ. TVERD. TELA (LENINGRAD)
6 (10), 3170-2, 1964.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE,
6 (10), 2531-2, 1965)

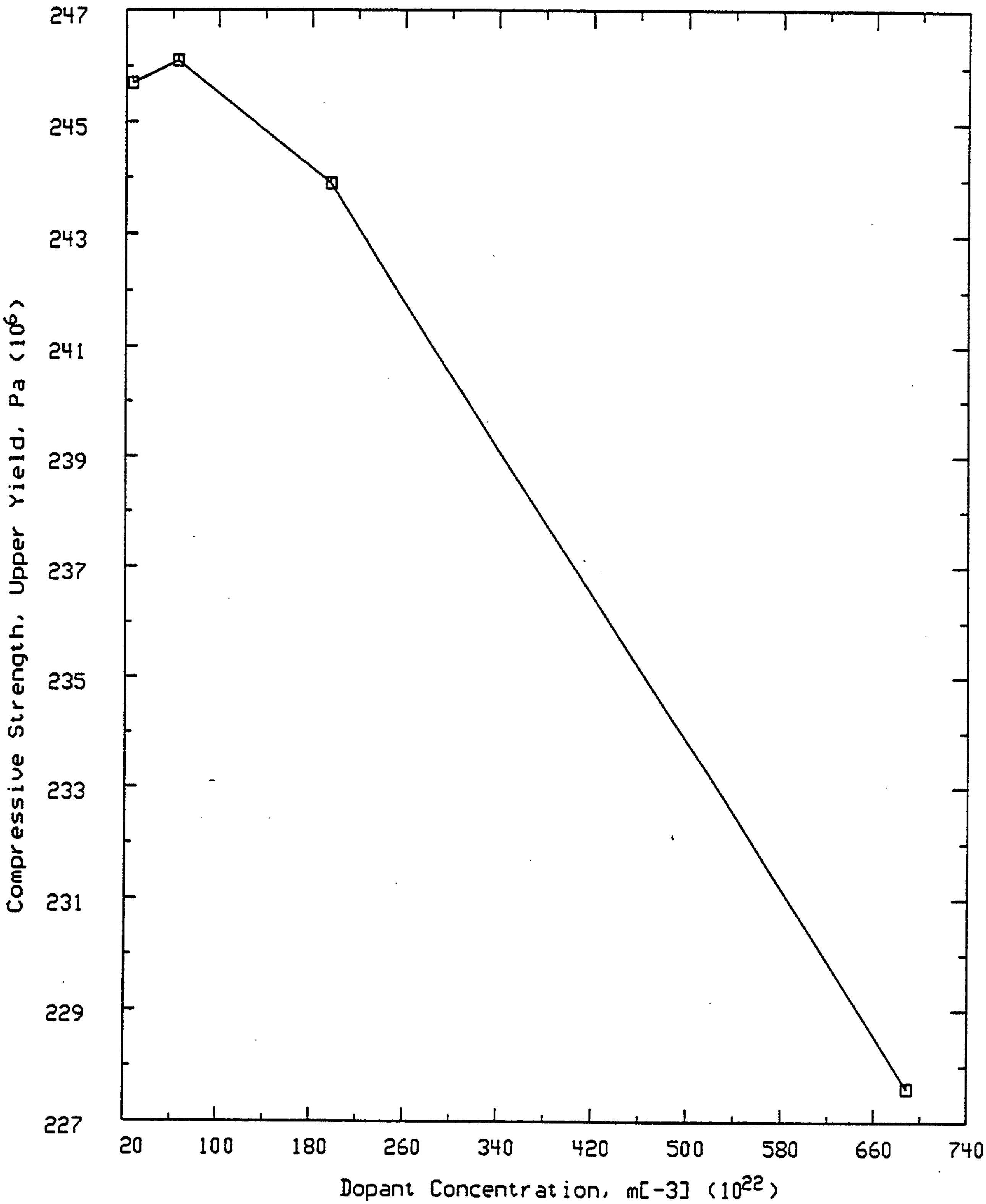

Figure 142 Compressive Strength, Upper Yield of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Compressive Strength, Upper Yield

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DATA SET 143

****

Composition

7.5e17	cm^{-3}	Oxygen Concentration
10.6e16	cm^{-3}	Carbon Concentration

Material Preparation

Crystal Growing Method :
Czochralski-grown, dislocation-free
Descriptors-Textual :
Isothermal annealing in vacuum (5.e-06 torr) as follows
Single-step annealing: 1073 K for 1 to 250 hrs.
Two-step annealing: 1073 K for 1 to 240 hrs. followed by annealing at 1323 K for 10 hrs.

Specimen Identification

Number/Name : cz-b
Dimensions (Geometry) :

Length	10.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	26.6	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Tests performed in air on an Instron machine (TTCM-L)
Parameters-Codified :
Annealing Temperature : 1073. K
Annealing Time : 1-250 hrs.
Strain Rate : 8.3e-05 s[-1]
Temperature : 1073. K (test temperature)

Original Source Reference/Additional Information

Dopant concentration of P or B not given

Measured/Evaluated Properties

X : Annealing Time s

Y : Compressive Strength, Upper Yield — Pa
Z1 : Temperature — K
Z2 : Strain Rate — s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
1.800e+03	1.315e+08	1.073e+03	8.300e-05	single annealing
1.800e+03	1.228e+08	1.073e+03	8.300e-05	
7.920e+03	1.272e+08	1.073e+03	8.300e-05	
1.548e+04	1.174e+08	1.073e+03	8.300e-05	
3.672e+04	1.207e+08	1.073e+03	8.300e-05	
3.960e+04	1.337e+08	1.073e+03	8.300e-05	
7.452e+04	1.043e+08	1.073e+03	8.300e-05	
1.454e+05	9.130e+07	1.073e+03	8.300e-05	
8.903e+05	7.600e+07	1.073e+03	8.300e-05	
1.800e+03	7.600e+07	1.073e+03	8.300e-05	double annealing
1.800e+03	9.130e+07	1.073e+03	8.300e-05	
3.600e+03	8.370e+07	1.073e+03	8.300e-05	
7.560e+03	9.020e+07	1.073e+03	8.300e-05	
1.512e+04	8.260e+07	1.073e+03	8.300e-05	
3.672e+04	7.600e+07	1.073e+03	8.300e-05	
7.164e+04	6.730e+07	1.073e+03	8.300e-05	
1.512e+05	5.210e+07	1.073e+03	8.300e-05	
3.744e+05	4.670e+07	1.073e+03	8.300e-05	
3.744e+05	4.130e+07	1.073e+03	8.300e-05	
8.903e+05	4.340e+07	1.073e+03	8.300e-05	
8.903e+05	3.910e+07	1.073e+03	8.300e-05	

Comments on Data

Data read from figures
Single annealing at 1073 K decreases the upper yield strength remarkably at larger annealing time. This is due to the introduction of large plate-like precipitates of SiO(2).

Reference

COMPRESSION TESTS OF HEAT-TREATED CZOCHRALSKI-GROWN SILICON CRYSTALS.
Yasutake, K. Umeno, M. Kawabe, H.
PHYS. STATUS SOLIDI A
69, 333-41, 1982.

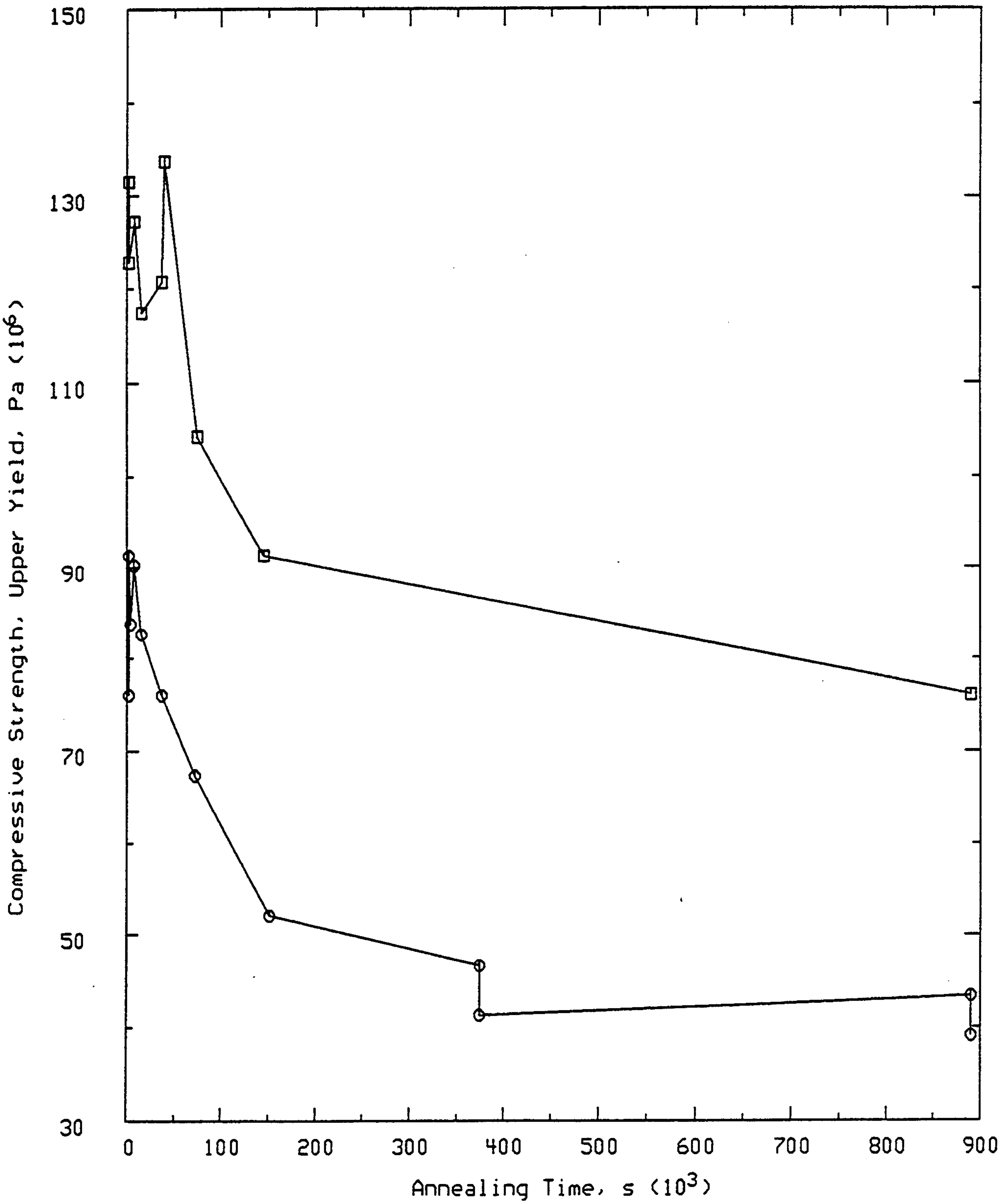

Figure 143 Compressive Strength, Upper Yield of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Compressive Strength, Upper Yield

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DATA SET 144

****

Composition

8.0e17	cm^{-3}	Oxygen Concentration
1.0e16	cm^{-3}	Carbon Concentration

Material Preparation

Crystal Growing Method :
Czochralski-grown, dislocation-free
Descriptors-Textual :
Isothermal annealing in vacuum (5.e-06 torr) as follows
Single-step annealing: 1073 K for 1 to 250 hrs.
Two-step annealing: 1073 K for 1 to 240 hrs. followed by annealing at 1323 K for 10 hrs.

Specimen Identification

Number/Name : cz-m
Dimensions (Geometry) :

Length	10.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	4.3	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Tests performed in air on an Instron machine (TTCM-L)
Parameters-Codified :
Annealing Temperature : 1073. K
Annealing Time : 1-250 hrs.
Strain Rate : 8.3e-05 s[-1]
Temperature : 1073. K (test temperature)

Original Source Reference/Additional Information

Dopant concentration of P or B not given

Measured/Evaluated Properties

X : Annealing Time s

Y	: Compressive Strength, Upper Yield	Pa
Z1	: Temperature	K
Z2	: Strain Rate	s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
1.800e+03	1.326e+08	1.073e+03	8.300e-05	single annealing
1.800e+03	1.228e+08	1.073e+03	8.300e-05	
7.560e+03	1.218e+08	1.073e+03	8.300e-05	
1.476e+04	1.207e+08	1.073e+03	8.300e-05	
3.708e+04	1.251e+08	1.073e+03	8.300e-05	
7.308e+04	1.327e+08	1.073e+03	8.300e-05	
7.308e+04	1.034e+08	1.073e+03	8.300e-05	
1.494e+05	1.143e+08	1.073e+03	8.300e-05	
3.730e+05	1.013e+08	1.073e+03	8.300e-05	
9.295e+05	9.150e+07	1.073e+03	8.300e-05	
1.800e+03	8.040e+07	1.073e+03	8.300e-05	double annealing
1.800e+03	7.060e+07	1.073e+03	8.300e-05	
7.200e+03	7.610e+07	1.073e+03	8.300e-05	
1.296e+04	8.040e+07	1.073e+03	8.300e-05	
3.600e+04	7.070e+07	1.073e+03	8.300e-05	
3.600e+04	6.530e+07	1.073e+03	8.300e-05	
7.308e+04	6.310e+07	1.073e+03	8.300e-05	
1.382e+05	6.200e+07	1.073e+03	8.300e-05	
3.589e+05	5.230e+07	1.073e+03	8.300e-05	
8.604e+05	4.150e+07	1.073e+03	8.300e-05	

Comments on Data

Data read from figures
Single annealing at 1073 K decreases the upper yield strength remarkably at larger annealing time. This is due to the introduction of large plate-like precipitates of SiO(2).

Reference

COMPRESSION TESTS OF HEAT-TREATED CZOCHRALSKI-GROWN SILICON CRYSTALS.
Yasutake, K. Umeno, M. Kawabe, H.
PHYS. STATUS SOLIDI A
69, 333-41, 1982.

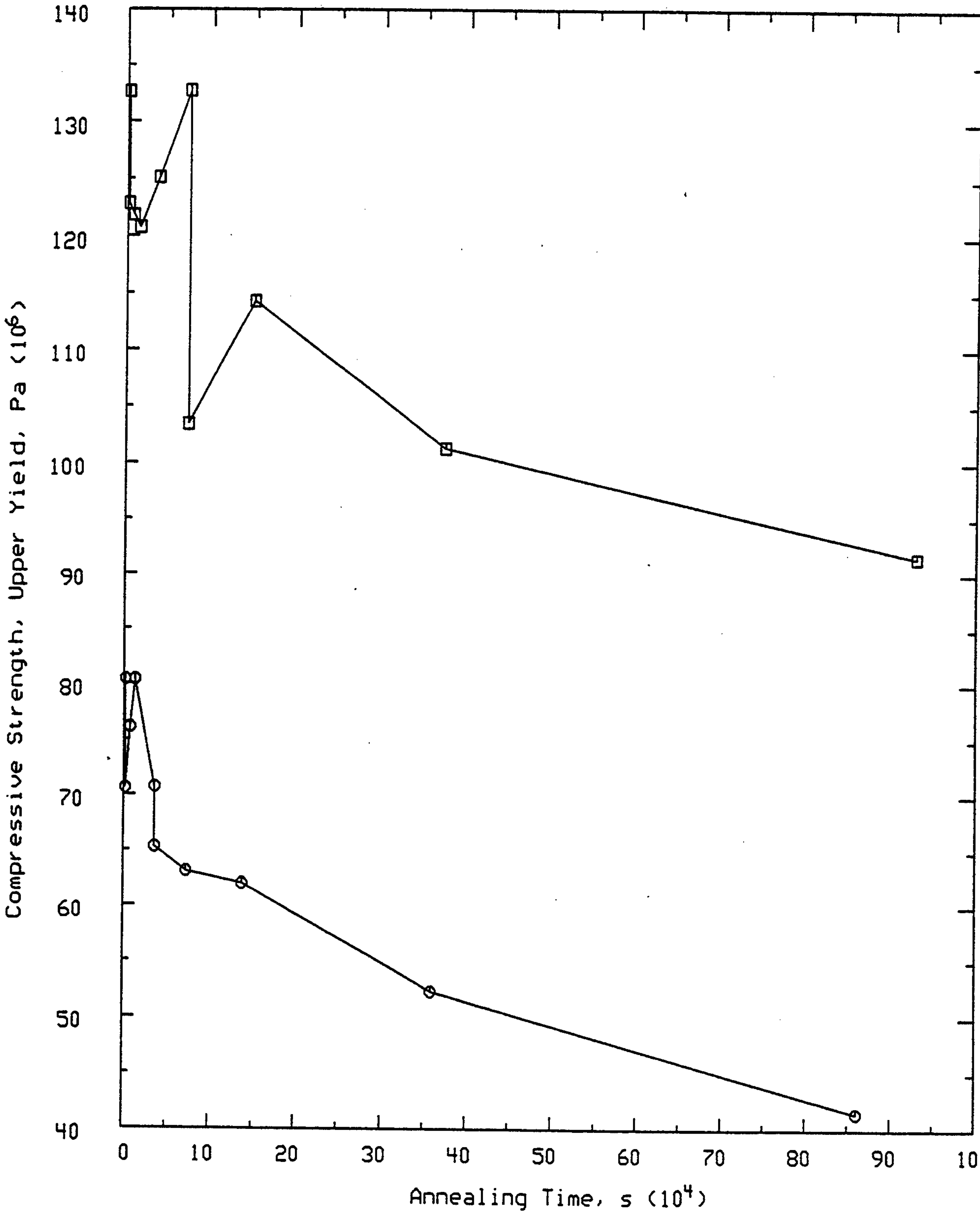

Figure 144 Compressive Strength, Upper Yield of Silicon: B doped

MATERIAL: Silicon: P doped

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PROPERTY: Compressive Strength, Upper Yield

DATA SET 145

****

Material Preparation

Crystal Growing Method :
Czochralski method, dislocation-free.

Additional Preparation/Conditioning

Surface Treatment :
Samples polished mechanically and chemically.

Specimen Identification

Dimensions (Geometry) :

Thickness	2.2	mm
Width	2.2	mm
Length	4.5	mm

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Compression test along <111> direction using a relaxometer.
Test done in an atmosphere of spectroscopically pure helium
Accuracy of the yield point measurements was +/- 3 pct.

Measured/Evaluated Properties

X : Dopant Concentration	m^{-3}
Y : Compressive Strength, Upper Yield	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
2.693e+21	1.952e+08	1.073e+03
1.296e+22	1.952e+08	1.073e+03
1.027e+23	1.964e+08	1.073e+03
8.750e+23	1.929e+08	1.073e+03
2.555e+24	1.856e+08	1.073e+03
1.230e+25	1.736e+08	1.073e+03
2.515e+25	1.639e+08	1.073e+03

Comments on Data

P-doping does not seem to have a profound effect on the yield point of silicon.

Dopant concentration determined by Hall effect measuremment.

Reference

SOME MECHANICAL PROPERTIES OF STRONGLY DOPED SILICON SINGLE CRYSTALS.
Mil'vidskii, M. G. Stolyarov, O. G.
Berkova, A. V.
FIZ. TVERD. TELA (LENINGRAD)
6 (10), 3170-2, 1964.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE,
6 (10), 2531-2, 1965)

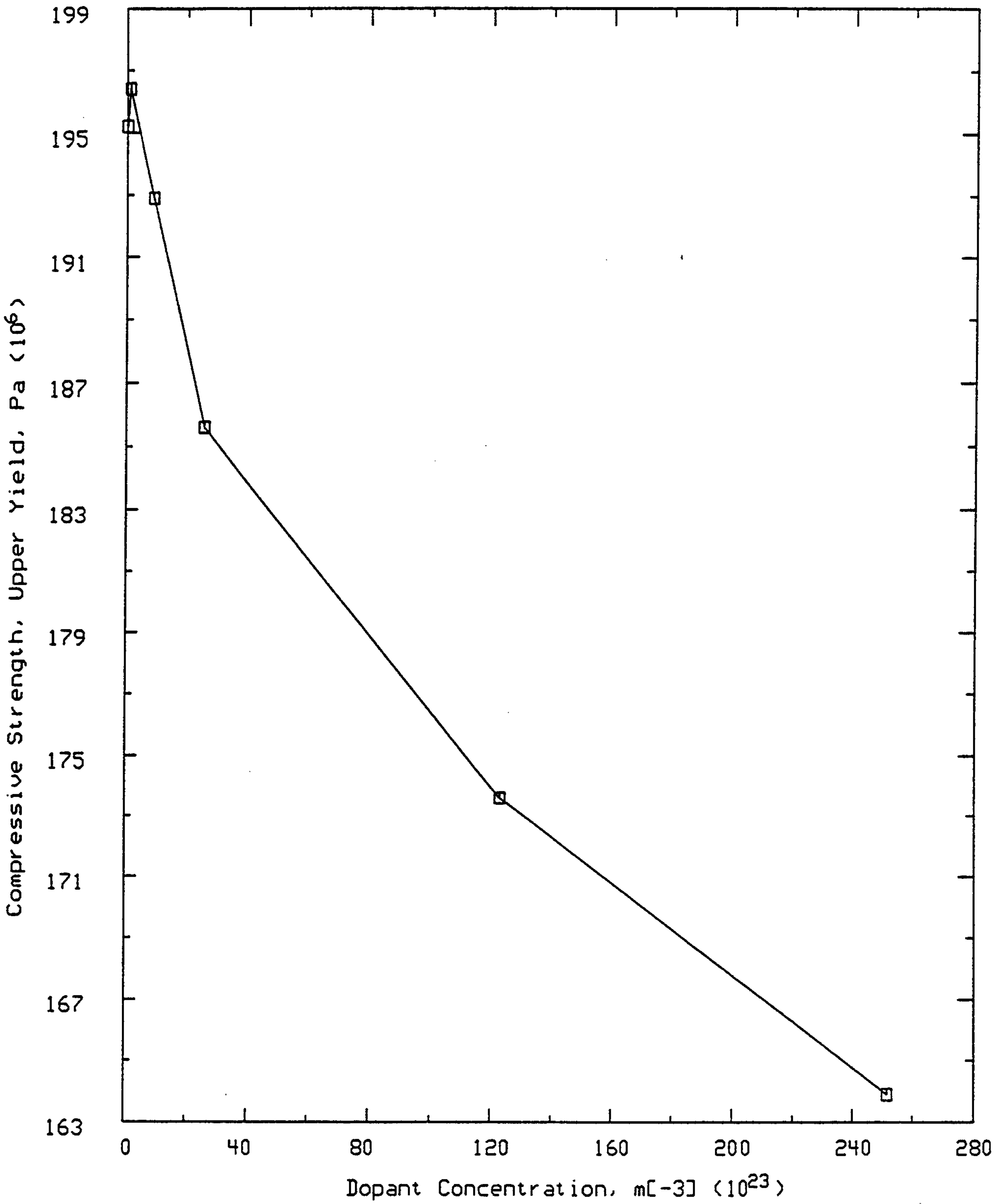

Figure 145 Compressive Strength, Upper Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Compressive Strength, Upper Yield

****

Composition

5.8e17	cm^{-3}	Oxygen Concentration
42.8e16	cm^{-3}	Carbon Concentration

Material Preparation

Crystal Growing Method :
Czochralski-grown, dislocation-free
Descriptors-Textual :
Isothermal annealing in vacuum (5.e-06 torr) as follows
Single-step annealing: 1073 K for 1 to 250 hrs.
Two-step annealing: 1073 K for 1 to 240 hrs. followed by
annealing at 1323 K for 10 hrs.

Specimen Identification

Number/Name : cz-a
Dimensions (Geometry) :

Length	10.0	mm
Width	3.0	mm
Thickness	3.0	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	2.9	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Tests performed in air on an Instron machine (TTCM-L)
Parameters-Codified :
Annealing Temperature : 1073. K
Annealing Time : 1-250 hrs.
Strain Rate : 8.3e-05 s[-1]
Temperature : 1073. K (test temperature)

Original Source Reference/Additional Information

Dopant concentration of P or B not given

Measured/Evaluated Properties

X : Annealing Time s

Y : Compressive Strength, Upper Yield | Pa
Z1 : Temperature | K
Z2 : Strain Rate | s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
1.800e+03	1.228e+08	1.073e+03	8.300e-05	single annealing
1.800e+03	1.184e+08	1.073e+03	8.300e-05	
1.800e+03	1.076e+08	1.073e+03	8.300e-05	
7.560e+03	1.240e+08	1.073e+03	8.300e-05	
1.476e+04	1.088e+08	1.073e+03	8.300e-05	
3.924e+04	1.186e+08	1.073e+03	8.300e-05	
1.476e+05	1.296e+08	1.073e+03	8.300e-05	
3.859e+05	1.209e+08	1.073e+03	8.300e-05	
8.950e+05	1.253e+08	1.073e+03	8.300e-05	
1.800e+03	8.360e+07	1.073e+03	8.300e-05	double annealing
7.200e+03	8.150e+07	1.073e+03	8.300e-05	
1.476e+04	8.810e+07	1.073e+03	8.300e-05	
3.780e+04	8.380e+07	1.073e+03	8.300e-05	
7.488e+04	8.280e+07	1.073e+03	8.300e-05	
1.480e+05	7.630e+07	1.073e+03	8.300e-05	
3.719e+05	9.150e+07	1.073e+03	8.300e-05	
9.000e+05	6.330e+07	1.073e+03	8.300e-05	

Comments on Data

Data read from figure.
Upper yield strength did not change with annealing time for single-step annealing while decreased with increasing time for double-step annealing.

Reference

COMPRESSION TESTS OF HEAT-TREATED CZOCHRALSKI-GROWN SILICON CRYSTALS.
Yasutake, K. Umeno, M. Kawabe, H.
PHYS. STATUS SOLIDI A
69, 333-41, 1982.

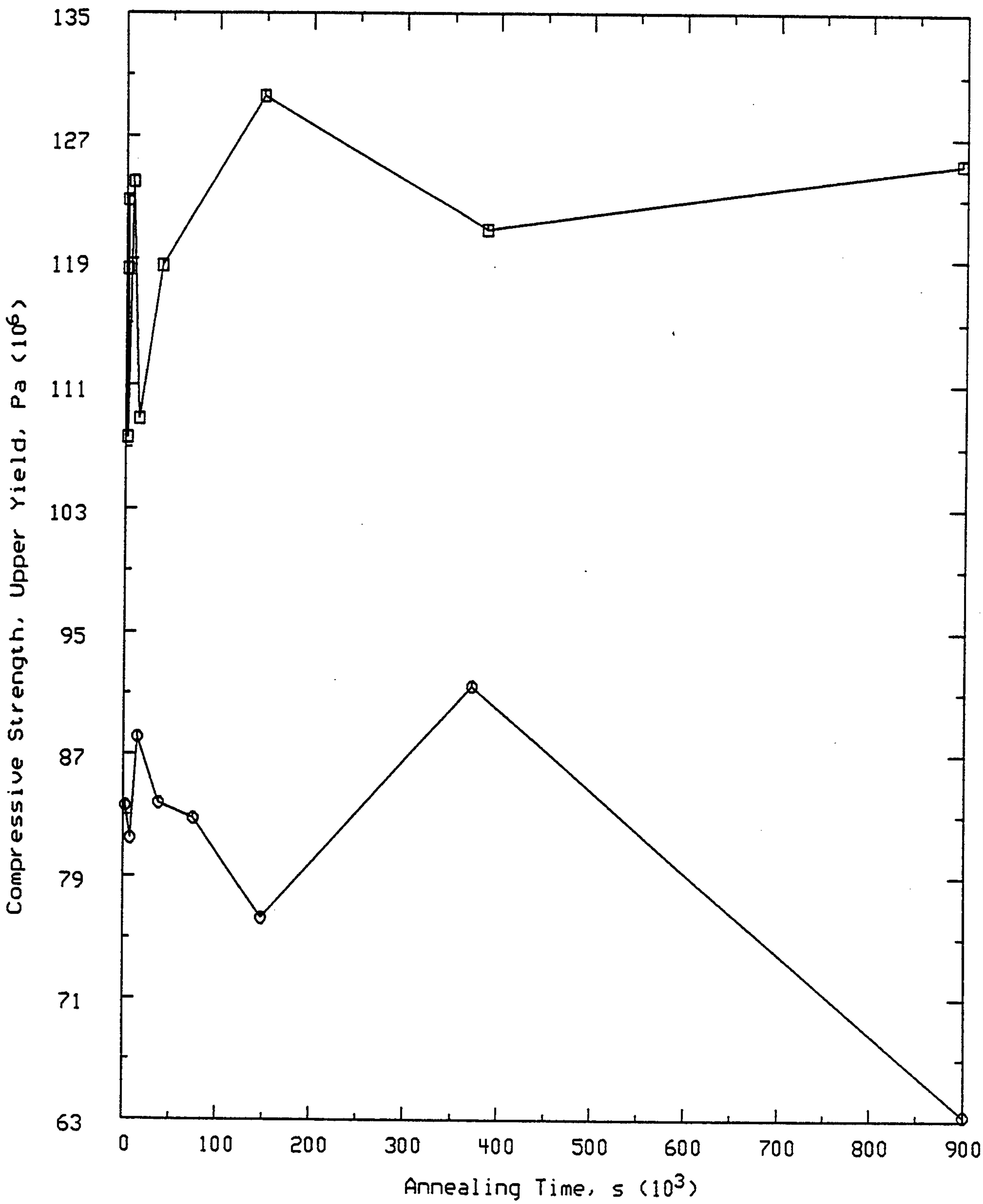

Figure 146 Compressive Strength, Upper Yield of Silicon: P doped

MATERIAL: Silicon: Sb doped

PROPERTY: Compressive Strength, Upper Yield

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DATA SET 147

****

Material Preparation

Crystal Growing Method :
Czochralski method, dislocation-free.

Additional Preparation/Conditioning

Surface Treatment :
Samples polished mechanically and chemically.

Specimen Identification

Dimensions (Geometry) :

Thickness	2.2	mm
Width	2.2	mm
Length	4.5	mm

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Compression test along <111> direction using a relaxometer.
Test done in an atmosphere of spectroscopically pure helium
Accuracy of the yield point measurements was +/- 3 pct.

Measured/Evaluated Properties

X : Dopant Concentration	m^{-3}
Y : Compressive Strength, Upper Yield	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
1.656e+21	1.958e+08	1.073e+03
9.735e+21	1.957e+08	1.073e+03
5.331e+22	1.969e+08	1.073e+03
1.544e+23	2.078e+08	1.073e+03
3.371e+23	2.210e+08	1.073e+03
7.886e+23	2.186e+08	1.073e+03
1.389e+24	2.102e+08	1.073e+03
3.245e+24	1.908e+08	1.073e+03
7.062e+24	1.714e+08	1.073e+03

Comments on Data

Sb-doping in the range 1.0e17-1.0e18 cm[-3] appear to increase the yield point of silicon.
Dopant concentration determined by Hall effect measuremment.
Concentrations above 1.0e18 lower the yield point.

Reference

SOME MECHANICAL PROPERTIES OF STRONGLY DOPED SILICON SINGLE CRYSTALS.
Mil'vidskii, M. G. Stolyarov, O. G.
Berkova, A. V.
FIZ. TVERD. TELA (LENINGRAD)
6 (10), 3170-2, 1964.
(FOR ENGLISH TRANSLATION SEE SOV. PHYS.-SOLID STATE,
6 (10), 2531-2, 1965)

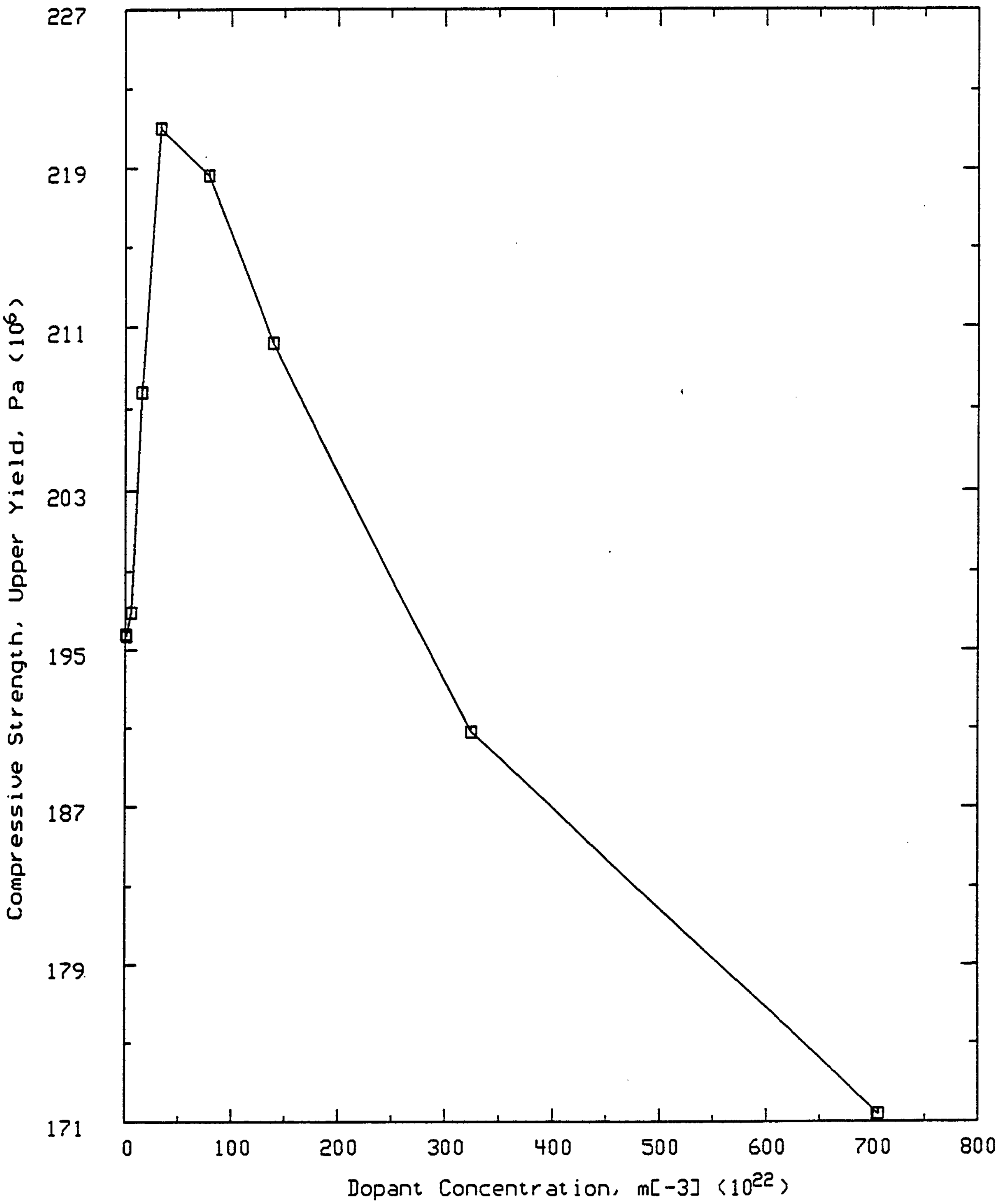

Figure 147 Compressive Strength, Upper Yield of Silicon: Sb doped

MATERIAL: Silicon, intrinsic

PROPERTY: Shear Stress, Resolved

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DATA SET 148

****

Material Preparation
Crystal Growing Method :
Czochralski grown, dislocation free

Specimen Identification
Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method
Name/Description :
Resolved Shear From Tensile Loading Test
Instron machine used

Measured/Evaluated Properties

X	: Shear Strain, Resolved	%
Y	: Shear Stress, Resolved	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}
Z2	: Temperature	K

Data Points :

X	Y	Z1	Z2
0.000e+00	0.000e+00	1.100e-04	1.173e+03
4.464e-01	1.024e+07	1.100e-04	1.173e+03
8.914e-01	2.008e+07	1.100e-04	1.173e+03
1.252e+00	3.032e+07	1.100e-04	1.173e+03
1.767e+00	3.524e+07	1.100e-04	1.173e+03
2.150e+00	3.032e+07	1.100e-04	1.173e+03
2.151e+00	2.417e+07	1.100e-04	1.173e+03
2.962e+00	2.007e+07	1.100e-04	1.173e+03
3.369e+00	1.761e+07	1.100e-04	1.173e+03
3.781e+00	1.679e+07	1.100e-04	1.173e+03
5.436e+00	1.638e+07	1.100e-04	1.173e+03
5.846e+00	1.515e+07	1.100e-04	1.173e+03
6.671e+00	1.391e+07	1.100e-04	1.173e+03
8.743e+00	1.432e+07	1.100e-04	1.173e+03
1.123e+01	1.513e+07	1.100e-04	1.173e+03
1.331e+01	1.635e+07	1.100e-04	1.173e+03
1.579e+01	1.716e+07	1.100e-04	1.173e+03
1.869e+01	1.757e+07	1.100e-04	1.173e+03
2.408e+01	1.919e+07	1.100e-04	1.173e+03
2.782e+01	2.082e+07	1.100e-04	1.173e+03

3.197e+01	2.285e+07	1.100e-04	1.173e+03
3.653e+01	2.694e+07	1.100e-04	1.173e+03
4.152e+01	3.266e+07	1.100e-04	1.173e+03
4.610e+01	3.879e+07	1.100e-04	1.173e+03
5.150e+01	4.533e+07	1.100e-04	1.173e+03
5.732e+01	5.146e+07	1.100e-04	1.173e+03
6.272e+01	5.636e+07	1.100e-04	1.173e+03

Comments on Data

Data read from Figure 3.
Deformation takes place by propagation of Luders bands in yield region.

Reference

SOLUTION EFFECTS ON THE MECHANICAL BEHAVIOR AND THE DISLOCATION MOBILITY IN SILICON CRYSTALS.
Sumino, K. Yonenaga, I. Harada, H.
Imai, M.
DISLOCAT. MODELL. PHYS. SYST., PROC. INT. CONF., 1980
212-6, 1981.
(Edited by M. F. Ashby, R. Bullough, C. S. Hartley
and J. P. Hirth; Pergamon Press: New York)

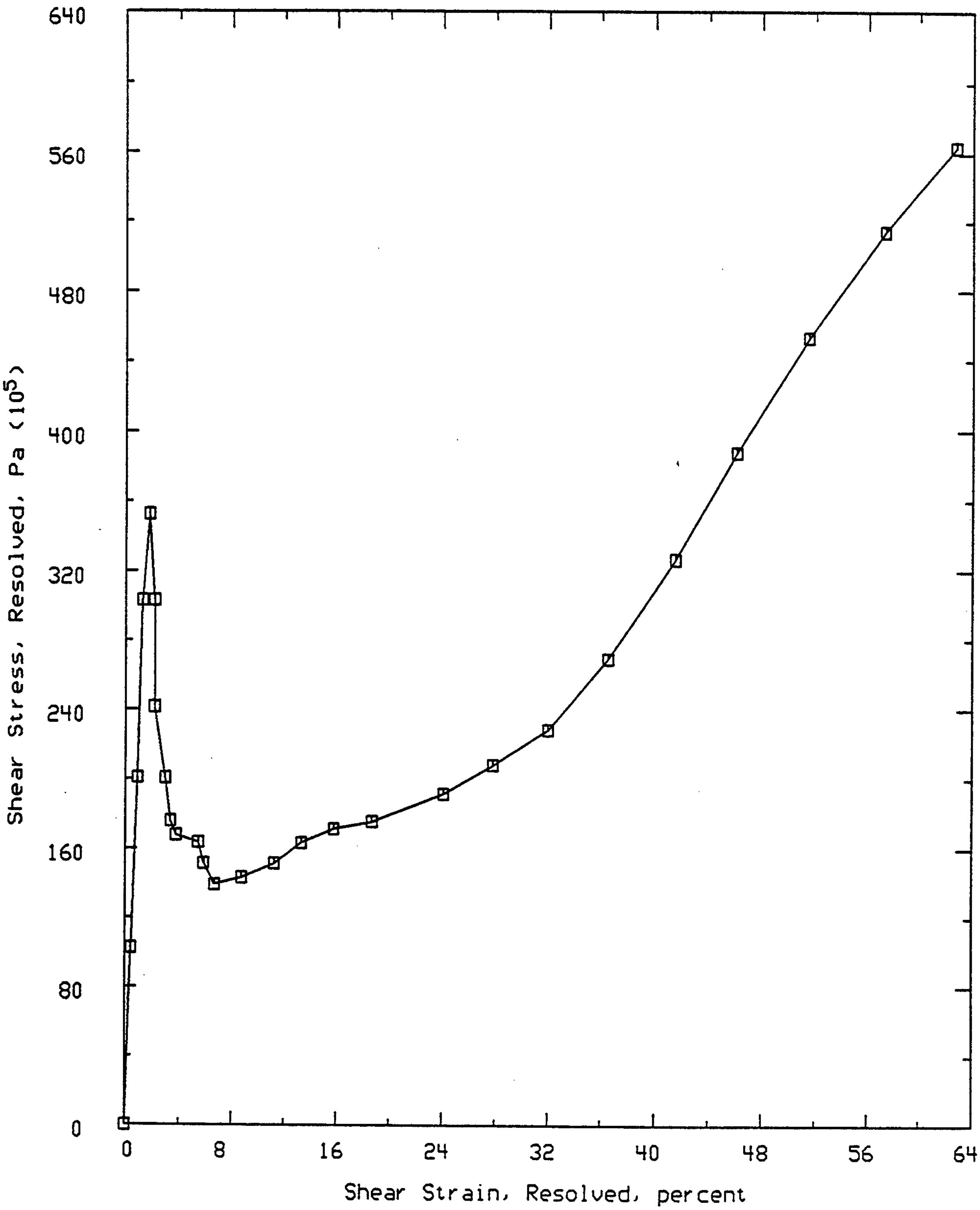

Figure 148 Shear Stress, Resolved of Silicon, intrinsic

MATERIAL: Silicon, intrinsic

PROPERTY: Shear Stress, Resolved

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****

Material Preparation

Crystal Growing Method :
Float zone grown, dislocation free

Specimen Identification

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :
Resolved Shear From Tensile Loading Test
Instron machine used

Measured/Evaluated Properties

X	: Shear Strain, Resolved	%
Y	: Shear Stress, Resolved	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}
Z2	: Temperature	K

Data Points :

X	Y	Z1	Z2
0.000e+00	0.000e+00	1.100e-04	1.173e+03
4.464e-01	1.024e+07	1.100e-04	1.173e+03
1.306e+00	2.008e+07	1.100e-04	1.173e+03
2.149e+00	2.868e+07	1.100e-04	1.173e+03
2.150e+00	2.499e+07	1.100e-04	1.173e+03
2.151e+00	1.885e+07	1.100e-04	1.173e+03
2.534e+00	1.557e+07	1.100e-04	1.173e+03
2.942e+00	1.352e+07	1.100e-04	1.173e+03
3.766e+00	1.228e+07	1.100e-04	1.173e+03
4.592e+00	1.146e+07	1.100e-04	1.173e+03
5.837e+00	1.228e+07	1.100e-04	1.173e+03
7.911e+00	1.309e+07	1.100e-04	1.173e+03
1.040e+01	1.308e+07	1.100e-04	1.173e+03
1.537e+01	1.471e+07	1.100e-04	1.173e+03
1.952e+01	1.551e+07	1.100e-04	1.173e+03
2.325e+01	1.591e+07	1.100e-04	1.173e+03
2.656e+01	1.754e+07	1.100e-04	1.173e+03
2.988e+01	1.876e+07	1.100e-04	1.173e+03
3.320e+01	2.080e+07	1.100e-04	1.173e+03
3.611e+01	2.407e+07	1.100e-04	1.173e+03

3.985e+01	2.816e+07	1.100e-04	1.173e+03
4.235e+01	3.143e+07	1.100e-04	1.173e+03
4.526e+01	3.675e+07	1.100e-04	1.173e+03
5.025e+01	4.329e+07	1.100e-04	1.173e+03
5.400e+01	4.819e+07	1.100e-04	1.173e+03
5.774e+01	5.187e+07	1.100e-04	1.173e+03
6.272e+01	5.636e+07	1.100e-04	1.173e+03

Comments on Data

Data read from Figure 3.
Deformation takes place by propagation of Luders bands in yield region.

Reference

SOLUTION EFFECTS ON THE MECHANICAL BEHAVIOR AND THE DISLOCATION MOBILITY IN SILICON CRYSTALS.
Sumino, K. Yonenaga, I. Harada, H.
Imai, M.
DISLOCAT. MODELL. PHYS. SYST., PROC. INT. CONF., 1980
212-6, 1981.
(Edited by M. F. Ashby, R. Bullough, C. S. Hartley
and J. P. Hirth; Pergamon Press: New York)

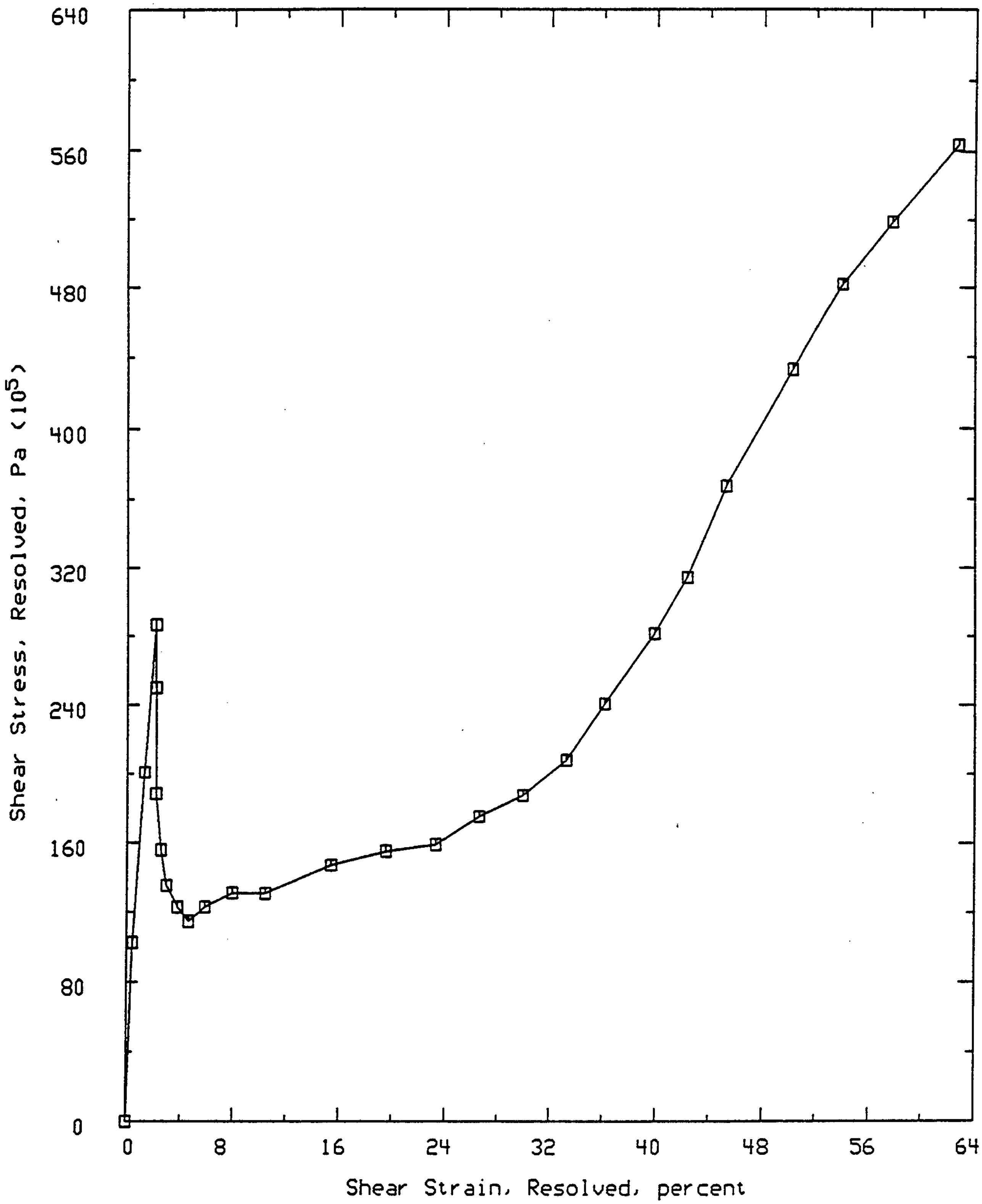

Figure 149 Shear Stress, Resolved of Silicon, intrinsic

MATERIAL: Silicon: P doped

PROPERTY: Shear Stress, Resolved

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DATA SET 150

****

Composition

1.e18	cm^{-3}	Oxygen Concentration
2.e16	cm^{-3}	Carbon Concentration

Vendor/Producer/Fabricator

KOFU Works of Hitachi Ltd.

Material Preparation

Crystal Growing Method :
Czochralski grown, dislocation free, n-type
Grown with diameter of 76 mm in the [111] direction.

Additional Preparation/Conditioning

Surface Treatment :
Surface layers polished and removed to depth more than 250 microns.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	7-9	Ω cm
Temperature	298	K

Measurement/Evaluation Method

Name/Description :
Shear Response Under Tensile Loading
Test conducted in vacuum using Instrom machine mounted to high temperature apparatus. Resolved shear properties derived from measured data.

Parameters-Codified :
Pressure : 1.333e-03 Pa
Shear Strain, Resolved : 1.1e-04 s[-1]
Temperature : 1173. K

Measured/Evaluated Properties

X : Shear Strain, Resolved	%
Y : Shear Stress, Resolved	Pa
Z1 : Temperature	K
Z2 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
0.000e+00	0.000e+00	1.173e+03	1.100e-04	as grown
6.300e-01	1.014e+07	1.173e+03	1.100e-04	
9.800e-01	2.010e+07	1.173e+03	1.100e-04	
1.750e+00	3.010e+07	1.173e+03	1.100e-04	
2.050e+00	3.280e+07	1.173e+03	1.100e-04	
2.210e+00	3.540e+07	1.173e+03	1.100e-04	
2.340e+00	3.480e+07	1.173e+03	1.100e-04	
2.350e+00	3.370e+07	1.173e+03	1.100e-04	
2.440e+00	3.010e+07	1.173e+03	1.100e-04	
2.460e+00	2.580e+07	1.173e+03	1.100e-04	
2.700e+00	2.260e+07	1.173e+03	1.100e-04	
2.970e+00	2.030e+07	1.173e+03	1.100e-04	
3.380e+00	1.800e+07	1.173e+03	1.100e-04	
3.800e+00	1.700e+07	1.173e+03	1.100e-04	
4.220e+00	1.650e+07	1.173e+03	1.100e-04	
4.930e+00	1.600e+07	1.173e+03	1.100e-04	
5.350e+00	1.540e+07	1.173e+03	1.100e-04	
6.060e+00	1.410e+07	1.173e+03	1.100e-04	
6.620e+00	1.370e+07	1.173e+03	1.100e-04	
7.620e+00	1.380e+07	1.173e+03	1.100e-04	
8.750e+00	1.420e+07	1.173e+03	1.100e-04	
9.890e+00	1.470e+07	1.173e+03	1.100e-04	
1.140e+01	1.550e+07	1.173e+03	1.100e-04	
1.300e+01	1.610e+07	1.173e+03	1.100e-04	
1.431e+01	1.660e+07	1.173e+03	1.100e-04	
1.673e+01	1.730e+07	1.173e+03	1.100e-04	
2.000e+01	1.820e+07	1.173e+03	1.100e-04	
2.270e+01	1.890e+07	1.173e+03	1.100e-04	
2.455e+01	1.940e+07	1.173e+03	1.100e-04	
2.683e+01	2.040e+07	1.173e+03	1.100e-04	
2.854e+01	2.110e+07	1.173e+03	1.100e-04	
2.997e+01	2.200e+07	1.173e+03	1.100e-04	
3.211e+01	2.320e+07	1.173e+03	1.100e-04	
3.382e+01	2.450e+07	1.173e+03	1.100e-04	
3.582e+01	2.630e+07	1.173e+03	1.100e-04	
3.796e+01	2.850e+07	1.173e+03	1.100e-04	
3.982e+01	3.030e+07	1.173e+03	1.100e-04	
4.140e+01	3.230e+07	1.173e+03	1.100e-04	
4.326e+01	3.500e+07	1.173e+03	1.100e-04	
4.541e+01	3.800e+07	1.173e+03	1.100e-04	

Comments on Data

Deformation preceded by means of the propagation of Luders bands in the yield region.

Reference

MECHANICAL BEHAVIOR OF CZOCHRALSKI-SILICON CRYSTALS AS AFFECTED BY PRECIPITATION AND DISSOLUTION OF OXYGEN ATOMS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS.
21 (1), 47-55, 1982.

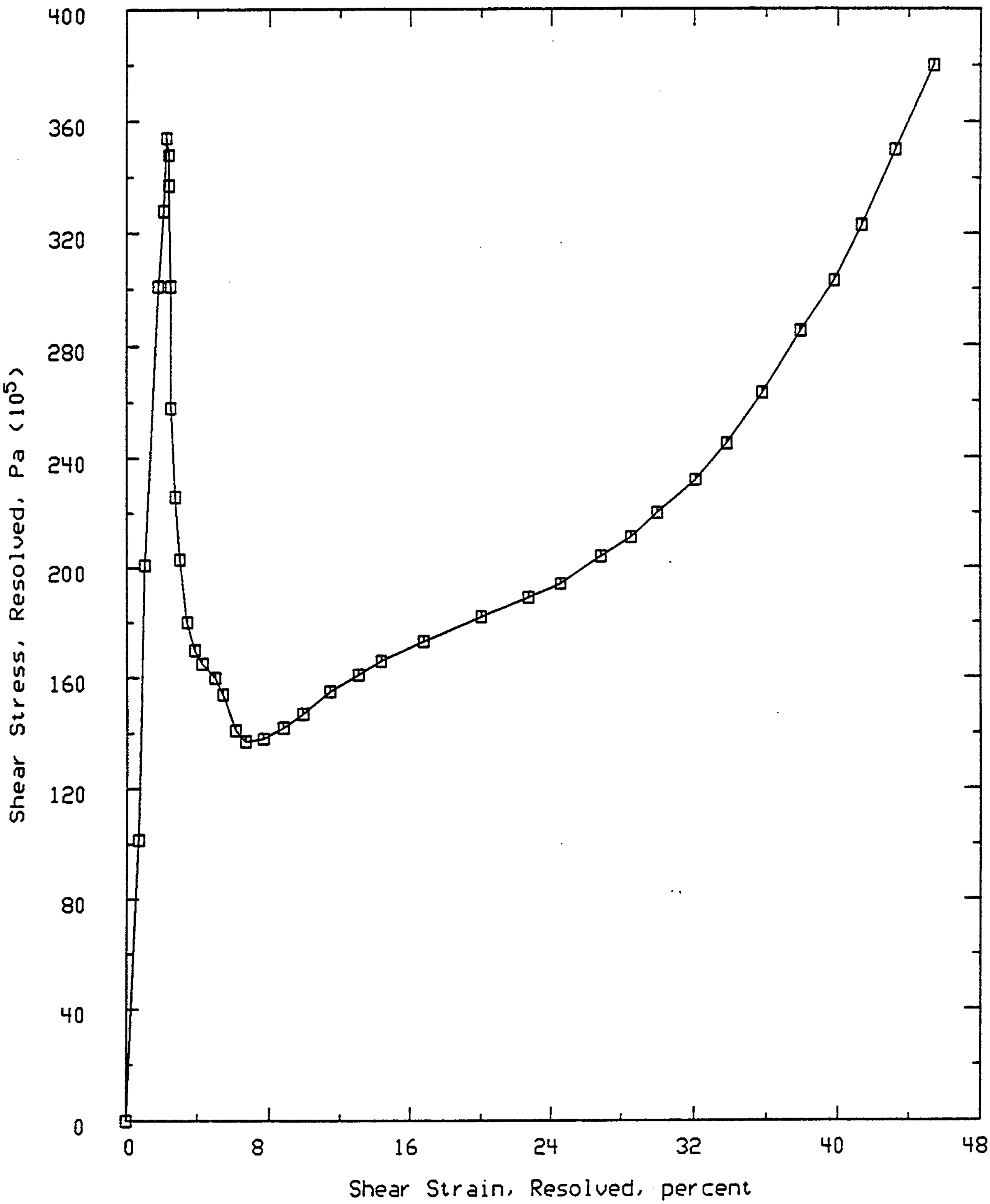

Figure 150 Shear Stress, Resolved of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Stress, Resolved

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DATA SET 151

****

Composition

1.e18	cm^{-3}	Oxygen Concentration
2.e16	cm^{-3}	Carbon Concentration

Vendor/Producer/Fabricator

KOFU Works of Hitachi Ltd.

Material Preparation

Crystal Growing Method :

Czochralski grown, dislocation free, n-type

Grown with diameter of 76 mm in the [111] direction.

Descriptors-Textual :

Annealed at various temperatures for 24 hours.

Additional Preparation/Conditioning

Surface Treatment :

Surface layers polished and removed to depth more than 250 microns.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	7-9	Ω cm
Temperature	298	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Test conducted in vacuum using Instrom machine mounted to high temperature apparatus. Resolved shear properties derived from measured data.

Parameters-Codified :

Pressure : 1.e-05 Torr

Shear Strain, Resolved : 1.1e-04 s[-1]

Temperature : 1173. K

Annealing Time : 24 hrs.

Measured/Evaluated Properties

X : Shear Strain, Resolved %

Y : Shear Stress, Resolved Pa
Z1 : Annealing Temperature K
Z2 : Temperature K
Z3 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1	Z2	Z3
0.000e+00	0.000e+00	1.323e+03	1.173e+03	1.100e-04
7.400e-01	4.600e+06	1.323e+03	1.173e+03	1.100e-04
1.320e+00	6.800e+06	1.323e+03	1.173e+03	1.100e-04
1.600e+00	6.600e+06	1.323e+03	1.173e+03	1.100e-04
1.890e+00	6.400e+06	1.323e+03	1.173e+03	1.100e-04
2.460e+00	6.400e+06	1.323e+03	1.173e+03	1.100e-04
4.450e+00	7.400e+06	1.323e+03	1.173e+03	1.100e-04
6.870e+00	8.400e+06	1.323e+03	1.173e+03	1.100e-04
9.718e+00	9.400e+06	1.323e+03	1.173e+03	1.100e-04
1.000e+01	9.400e+06	1.323e+03	1.173e+03	1.100e-04
1.228e+01	1.010e+07	1.323e+03	1.173e+03	1.100e-04
1.498e+01	1.060e+07	1.323e+03	1.173e+03	1.100e-04
1.783e+01	1.120e+07	1.323e+03	1.173e+03	1.100e-04
1.996e+01	1.140e+07	1.323e+03	1.173e+03	1.100e-04
2.365e+01	1.190e+07	1.323e+03	1.173e+03	1.100e-04
2.725e+01	1.240e+07	1.323e+03	1.173e+03	1.100e-04
2.991e+01	1.300e+07	1.323e+03	1.173e+03	1.100e-04
3.304e+01	1.380e+07	1.323e+03	1.173e+03	1.100e-04
3.546e+01	1.460e+07	1.323e+03	1.173e+03	1.100e-04
3.774e+01	1.590e+07	1.323e+03	1.173e+03	1.100e-04
3.974e+01	1.750e+07	1.323e+03	1.173e+03	1.100e-04
4.189e+01	1.970e+07	1.323e+03	1.173e+03	1.100e-04
4.446e+01	2.320e+07	1.323e+03	1.173e+03	1.100e-04
4.705e+01	2.720e+07	1.323e+03	1.173e+03	1.100e-04
4.992e+01	3.230e+07	1.323e+03	1.173e+03	1.100e-04
5.064e+01	3.370e+07	1.323e+03	1.173e+03	1.100e-04
0.000e+00	0.000e+00	1.448e+03	1.173e+03	1.100e-04
6.300e-01	1.030e+07	1.448e+03	1.173e+03	1.100e-04
9.500e-01	1.610e+07	1.448e+03	1.173e+03	1.100e-04
1.740e+00	2.770e+07	1.448e+03	1.173e+03	1.100e-04
2.040e+00	3.000e+07	1.448e+03	1.173e+03	1.100e-04
2.340e+00	3.360e+07	1.448e+03	1.173e+03	1.100e-04
2.490e+00	3.500e+07	1.448e+03	1.173e+03	1.100e-04
2.640e+00	3.580e+07	1.448e+03	1.173e+03	1.100e-04
2.780e+00	3.500e+07	1.448e+03	1.173e+03	1.100e-04
2.900e+00	3.180e+07	1.448e+03	1.173e+03	1.100e-04
2.900e+00	3.000e+07	1.448e+03	1.173e+03	1.100e-04

2.980e+00	2.530e+07	1.448e+03	1.173e+03	1.100e-04
3.140e+00	2.200e+07	1.448e+03	1.173e+03	1.100e-04
3.400e+00	2.070e+07	1.448e+03	1.173e+03	1.100e-04
3.670e+00	1.930e+07	1.448e+03	1.173e+03	1.100e-04
3.950e+00	1.870e+07	1.448e+03	1.173e+03	1.100e-04
4.660e+00	1.770e+07	1.448e+03	1.173e+03	1.100e-04
5.360e+00	1.630e+07	1.448e+03	1.173e+03	1.100e-04
5.920e+00	1.570e+07	1.448e+03	1.173e+03	1.100e-04
6.630e+00	1.520e+07	1.448e+03	1.173e+03	1.100e-04
7.200e+00	1.520e+07	1.448e+03	1.173e+03	1.100e-04
7.470e+00	1.480e+07	1.448e+03	1.173e+03	1.100e-04
7.760e+00	1.470e+07	1.448e+03	1.173e+03	1.100e-04
8.190e+00	1.450e+07	1.448e+03	1.173e+03	1.100e-04
8.620e+00	1.470e+07	1.448e+03	1.173e+03	1.100e-04
9.390e+00	1.510e+07	1.448e+03	1.173e+03	1.100e-04
1.160e+01	1.560e+07	1.448e+03	1.173e+03	1.100e-04
1.374e+01	1.630e+07	1.448e+03	1.173e+03	1.100e-04
1.602e+01	1.690e+07	1.448e+03	1.173e+03	1.100e-04
1.829e+01	1.750e+07	1.448e+03	1.173e+03	1.100e-04
1.986e+01	1.770e+07	1.448e+03	1.173e+03	1.100e-04
2.199e+01	1.840e+07	1.448e+03	1.173e+03	1.100e-04
2.455e+01	1.930e+07	1.448e+03	1.173e+03	1.100e-04
2.726e+01	2.080e+07	1.448e+03	1.173e+03	1.100e-04
2.997e+01	2.280e+07	1.448e+03	1.173e+03	1.100e-04
3.254e+01	2.490e+07	1.448e+03	1.173e+03	1.100e-04
3.440e+01	2.680e+07	1.448e+03	1.173e+03	1.100e-04
3.640e+01	2.890e+07	1.448e+03	1.173e+03	1.100e-04
3.841e+01	3.100e+07	1.448e+03	1.173e+03	1.100e-04
3.969e+01	3.280e+07	1.448e+03	1.173e+03	1.100e-04
4.141e+01	3.500e+07	1.448e+03	1.173e+03	1.100e-04
4.256e+01	3.670e+07	1.448e+03	1.173e+03	1.100e-04

0.000e+00	0.000e+00	1.593e+03	1.173e+03	1.100e-04
4.900e-01	1.000e+07	1.593e+03	1.173e+03	1.100e-04
9.800e-01	2.010e+07	1.593e+03	1.173e+03	1.100e-04
1.470e+00	3.000e+07	1.593e+03	1.173e+03	1.100e-04
1.770e+00	3.300e+07	1.593e+03	1.173e+03	1.100e-04
1.900e+00	3.160e+07	1.593e+03	1.173e+03	1.100e-04
2.020e+00	2.780e+07	1.593e+03	1.173e+03	1.100e-04
2.090e+00	2.280e+07	1.593e+03	1.173e+03	1.100e-04
2.170e+00	2.010e+07	1.593e+03	1.173e+03	1.100e-04
2.240e+00	1.840e+07	1.593e+03	1.173e+03	1.100e-04
2.250e+00	1.780e+07	1.593e+03	1.173e+03	1.100e-04
2.810e+00	1.730e+07	1.593e+03	1.173e+03	1.100e-04
3.090e+00	1.670e+07	1.593e+03	1.173e+03	1.100e-04
3.650e+00	1.560e+07	1.593e+03	1.173e+03	1.100e-04

4.070e+00	1.430e+07	1.593e+03	1.173e+03	1.100e-04
5.050e+00	1.280e+07	1.593e+03	1.173e+03	1.100e-04
5.900e+00	1.230e+07	1.593e+03	1.173e+03	1.100e-04
6.890e+00	1.180e+07	1.593e+03	1.173e+03	1.100e-04
7.750e+00	1.180e+07	1.593e+03	1.173e+03	1.100e-04
9.740e+00	1.210e+07	1.593e+03	1.173e+03	1.100e-04
1.272e+01	1.280e+07	1.593e+03	1.173e+03	1.100e-04
1.486e+01	1.330e+07	1.593e+03	1.173e+03	1.100e-04
1.656e+01	1.380e+07	1.593e+03	1.173e+03	1.100e-04
1.841e+01	1.390e+07	1.593e+03	1.173e+03	1.100e-04
1.998e+01	1.420e+07	1.593e+03	1.173e+03	1.100e-04
2.196e+01	1.420e+07	1.593e+03	1.173e+03	1.100e-04
2.410e+01	1.430e+07	1.593e+03	1.173e+03	1.100e-04
2.594e+01	1.440e+07	1.593e+03	1.173e+03	1.100e-04
2.836e+01	1.480e+07	1.593e+03	1.173e+03	1.100e-04
3.007e+01	1.520e+07	1.593e+03	1.173e+03	1.100e-04
3.235e+01	1.640e+07	1.593e+03	1.173e+03	1.100e-04
3.435e+01	1.780e+07	1.593e+03	1.173e+03	1.100e-04
3.634e+01	1.950e+07	1.593e+03	1.173e+03	1.100e-04
3.821e+01	2.180e+07	1.593e+03	1.173e+03	1.100e-04
3.978e+01	2.350e+07	1.593e+03	1.173e+03	1.100e-04
4.207e+01	2.630e+07	1.593e+03	1.173e+03	1.100e-04
4.408e+01	2.930e+07	1.593e+03	1.173e+03	1.100e-04
4.608e+01	3.200e+07	1.593e+03	1.173e+03	1.100e-04

Comments on Data

Annealing at 1323 K drastically reduces the yield strength throughout all deformation stages.
Annealing at 1448 and 1593 K does not affect the magnitude of the upper yield of the stress significantly.

Reference

MECHANICAL BEHAVIOR OF CZOCHRALSKI-SILICON CRYSTALS AS AFFECTED BY PRECIPITATION AND DISSOLUTION OF OXYGEN ATOMS.
Yonenaga, I.   Sumino, K.
JPN. J. APPL. PHYS.
21 (1), 47-55, 1982.

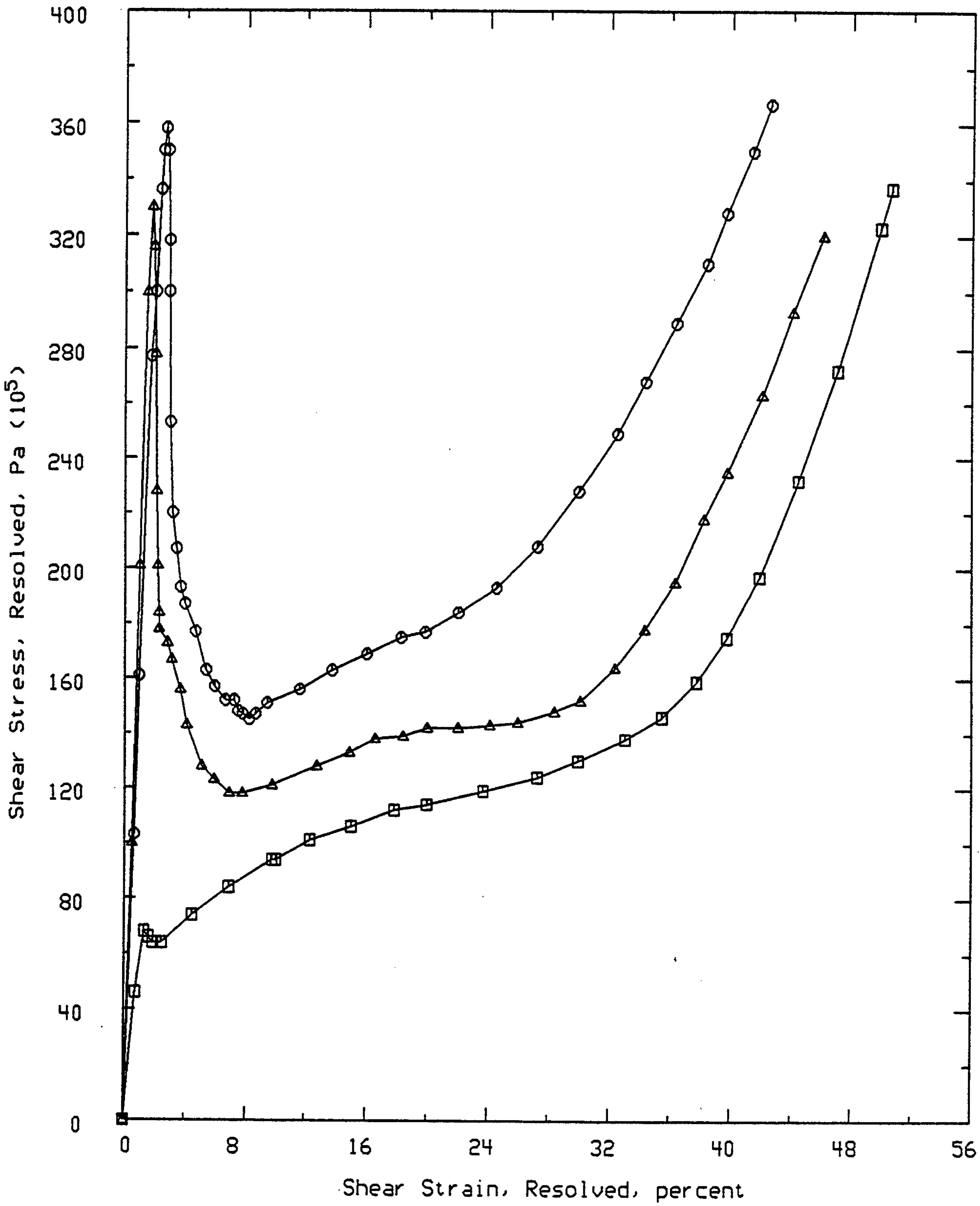

Figure 151 Shear Stress, Resolved of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Stress, Resolved

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PURDUE UNIVERSITY
DATA SET 152

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Composition

1.e18	cm^{-3}	Oxygen Concentration
2.e16	cm^{-3}	Carbon Concentration

Vendor/Producer/Fabricator

KOFU Works of Hitachi Ltd.

Material Preparation

Crystal Growing Method :

Czochralski grown, dislocation free, n-type
Grown with diameter of 76 mm in the [111] direction.

Descriptors-Textual :

Annealed at 1323. K for various times.

Additional Preparation/Conditioning

Surface Treatment :

Surface layers polished and removed to depth more than 250 microns.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	7-9	Ω cm
Temperature	298	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading
Test conducted in vacuum using Instrom machine mounted to high temperature apparatus. Resolved shear properties derived from measured data.

Parameters-Codified :

Pressure : 1.e-05 Torr
Shear Strain, Resolved : 1.1e-04 s[-1]
Temperature : 1173. K
Annealing Temperature : 1323. K

Measured/Evaluated Properties

X : Shear Strain, Resolved %

Y : Shear Stress, Resolved Pa
Z1 : Annealing Time s
Z2 : Temperature K
Z3 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1	Z2	Z3
0.000e+00	0.000e+00	1.080e+04	1.173e+03	1.100e-04
8.000e-01	1.010e+07	1.080e+04	1.173e+03	1.100e-04
1.270e+00	1.620e+07	1.080e+04	1.173e+03	1.100e-04
1.590e+00	2.030e+07	1.080e+04	1.173e+03	1.100e-04
2.060e+00	2.570e+07	1.080e+04	1.173e+03	1.100e-04
2.360e+00	2.710e+07	1.080e+04	1.173e+03	1.100e-04
2.480e+00	2.560e+07	1.080e+04	1.173e+03	1.100e-04
2.500e+00	2.250e+07	1.080e+04	1.173e+03	1.100e-04
2.620e+00	2.010e+07	1.080e+04	1.173e+03	1.100e-04
3.040e+00	1.560e+07	1.080e+04	1.173e+03	1.100e-04
3.320e+00	1.350e+07	1.080e+04	1.173e+03	1.100e-04
3.610e+00	1.250e+07	1.080e+04	1.173e+03	1.100e-04
4.490e+00	1.200e+07	1.080e+04	1.173e+03	1.100e-04
4.930e+00	1.170e+07	1.080e+04	1.173e+03	1.100e-04
6.160e+00	1.230e+07	1.080e+04	1.173e+03	1.100e-04
7.890e+00	1.330e+07	1.080e+04	1.173e+03	1.100e-04
9.960e+00	1.410e+07	1.080e+04	1.173e+03	1.100e-04
1.262e+01	1.480e+07	1.080e+04	1.173e+03	1.100e-04
1.587e+01	1.540e+07	1.080e+04	1.173e+03	1.100e-04
1.882e+01	1.580e+07	1.080e+04	1.173e+03	1.100e-04
2.015e+01	1.610e+07	1.080e+04	1.173e+03	1.100e-04
2.340e+01	1.680e+07	1.080e+04	1.173e+03	1.100e-04
2.650e+01	1.810e+07	1.080e+04	1.173e+03	1.100e-04
3.005e+01	2.030e+07	1.080e+04	1.173e+03	1.100e-04
3.376e+01	2.380e+07	1.080e+04	1.173e+03	1.100e-04
3.643e+01	2.690e+07	1.080e+04	1.173e+03	1.100e-04
3.866e+01	2.960e+07	1.080e+04	1.173e+03	1.100e-04
4.059e+01	3.210e+07	1.080e+04	1.173e+03	1.100e-04
0.000e+00	0.000e+00	2.160e+04	1.173e+03	1.100e-04
6.300e-01	6.500e+06	2.160e+04	1.173e+03	1.100e-04
1.230e+00	9.700e+06	2.160e+04	1.173e+03	1.100e-04
1.240e+00	1.040e+07	2.160e+04	1.173e+03	1.100e-04
1.530e+00	9.600e+06	2.160e+04	1.173e+03	1.100e-04
1.670e+00	8.400e+06	2.160e+04	1.173e+03	1.100e-04
1.960e+00	7.500e+06	2.160e+04	1.173e+03	1.100e-04
2.400e+00	7.300e+06	2.160e+04	1.173e+03	1.100e-04
4.470e+00	8.500e+06	2.160e+04	1.173e+03	1.100e-04

6.990e+00	9.500e+06	2.160e+04	1.173e+03	1.100e-04
1.009e+01	1.040e+07	2.160e+04	1.173e+03	1.100e-04
1.275e+01	1.130e+07	2.160e+04	1.173e+03	1.100e-04
1.688e+01	1.200e+07	2.160e+04	1.173e+03	1.100e-04
1.998e+01	1.240e+07	2.160e+04	1.173e+03	1.100e-04
2.455e+01	1.280e+07	2.160e+04	1.173e+03	1.100e-04
2.795e+01	1.320e+07	2.160e+04	1.173e+03	1.100e-04
3.002e+01	1.370e+07	2.160e+04	1.173e+03	1.100e-04
3.297e+01	1.450e+07	2.160e+04	1.173e+03	1.100e-04
3.578e+01	1.580e+07	2.160e+04	1.173e+03	1.100e-04
3.815e+01	1.740e+07	2.160e+04	1.173e+03	1.100e-04
4.008e+01	1.950e+07	2.160e+04	1.173e+03	1.100e-04
4.245e+01	2.240e+07	2.160e+04	1.173e+03	1.100e-04
4.498e+01	2.610e+07	2.160e+04	1.173e+03	1.100e-04
4.707e+01	2.960e+07	2.160e+04	1.173e+03	1.100e-04
4.886e+01	3.310e+07	2.160e+04	1.173e+03	1.100e-04
5.020e+01	3.560e+07	2.160e+04	1.173e+03	1.100e-04
5.139e+01	3.830e+07	2.160e+04	1.173e+03	1.100e-04

0.000e+00	0.000e+00	4.320e+04	1.173e+03	1.100e-04
6.200e-01	5.000e+06	4.320e+04	1.173e+03	1.100e-41
9.200e-01	7.200e+06	4.320e+04	1.173e+03	1.100e-04
9.200e-01	7.200e+06	4.320e+04	1.173e+03	1.100e-04
1.220e+00	7.200e+06	4.320e+04	1.173e+03	1.100e-04
1.370e+00	6.900e+06	4.320e+04	1.173e+03	1.100e-04
1.510e+00	6.600e+06	4.320e+04	1.173e+03	1.100e-04
2.400e+00	6.600e+06	4.320e+04	1.173e+03	1.100e-04
3.730e+00	7.300e+06	4.320e+04	1.173e+03	1.100e-04
5.800e+00	8.400e+06	4.320e+04	1.173e+03	1.100e-04
7.720e+00	9.100e+06	4.320e+04	1.173e+03	1.100e-04
9.790e+00	9.800e+06	4.320e+04	1.173e+03	1.100e-04
1.215e+01	1.040e+07	4.320e+04	1.173e+03	1.100e-04
1.525e+01	1.100e+07	4.320e+04	1.173e+03	1.100e-04
1.820e+01	1.140e+07	4.320e+04	1.173e+03	1.100e-04
1.998e+01	1.170e+07	4.320e+04	1.173e+03	1.100e-04
2.381e+01	1.210e+07	4.320e+04	1.173e+03	1.100e-04
2.750e+01	1.250e+07	4.320e+04	1.173e+03	1.100e-04
3.001e+01	1.310e+07	4.320e+04	1.173e+03	1.100e-04
3.326e+01	1.390e+07	4.320e+04	1.173e+03	1.100e-04
3.592e+01	1.500e+07	4.320e+04	1.173e+03	1.100e-04
3.785e+01	1.630e+07	4.320e+04	1.173e+03	1.100e-04
4.022e+01	1.820e+07	4.320e+04	1.173e+03	1.100e-04
4.304e+01	2.150e+07	4.320e+04	1.173e+03	1.100e-04
4.468e+01	2.490e+07	4.320e+04	1.173e+03	1.100e-04
4.646e+01	2.730e+07	4.320e+04	1.173e+03	1.100e-04
4.840e+01	3.090e+07	4.320e+04	1.173e+03	1.100e-04

5.004e+01	3.410e+07	4.320e+04	1.173e+03	1.100e-04
5.153e+01	3.710e+07	4.320e+04	1.173e+03	1.100e-04
0.000e+00	0.000e+00	8.640e+04	1.173e+03	1.100e-04
7.300e-01	5.100e+06	8.640e+04	1.173e+03	1.100e-04
1.070e+00	6.600e+06	8.640e+04	1.173e+03	1.100e-04
1.370e+00	6.900e+06	8.640e+04	1.173e+03	1.100e-04
1.810e+00	6.600e+06	8.640e+04	1.173e+03	1.100e-04
2.100e+00	6.600e+06	8.640e+04	1.173e+03	1.100e-04
3.280e+00	6.600e+06	8.640e+04	1.173e+03	1.100e-04
4.910e+00	7.500e+06	8.640e+04	1.173e+03	1.100e-04
7.270e+00	8.500e+06	8.640e+04	1.173e+03	1.100e-04
1.008e+01	9.200e+06	8.640e+04	1.173e+03	1.100e-04
1.289e+01	1.020e+07	8.640e+04	1.173e+03	1.100e-04
1.673e+01	1.090e+07	8.640e+04	1.173e+03	1.100e-04
1.998e+01	1.150e+07	8.640e+04	1.173e+03	1.100e-04
2.307e+01	1.180e+07	8.640e+04	1.173e+03	1.100e-04
2.691e+01	1.240e+07	8.640e+04	1.173e+03	1.100e-04
3.001e+01	1.280e+07	8.640e+04	1.173e+03	1.100e-04
3.385e+01	1.390e+07	8.640e+04	1.173e+03	1.100e-04
3.755e+01	1.550e+07	8.640e+04	1.173e+03	1.100e-04
4.036e+01	1.760e+07	8.640e+04	1.173e+03	1.100e-04
4.170e+01	1.870e+07	8.640e+04	1.173e+03	1.100e-04
4.333e+01	2.090e+07	8.640e+04	1.173e+03	1.100e-04
4.616e+01	2.500e+07	8.640e+04	1.173e+03	1.100e-04
4.824e+01	2.870e+07	8.640e+04	1.173e+03	1.100e-04
5.018e+01	3.180e+07	8.640e+04	1.173e+03	1.100e-04
5.092e+01	3.340e+07	8.640e+04	1.173e+03	1.100e-04

Comments on Data

Specimens show rapid softening with increase of annealing time.

Reference

MECHANICAL BEHAVIOR OF CZOCHRALSKI-SILICON CRYSTALS AS AFFECTED BY PRECIPITATION AND DISSOLUTION OF OXYGEN ATOMS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS.
21 (1), 47-55, 1982.

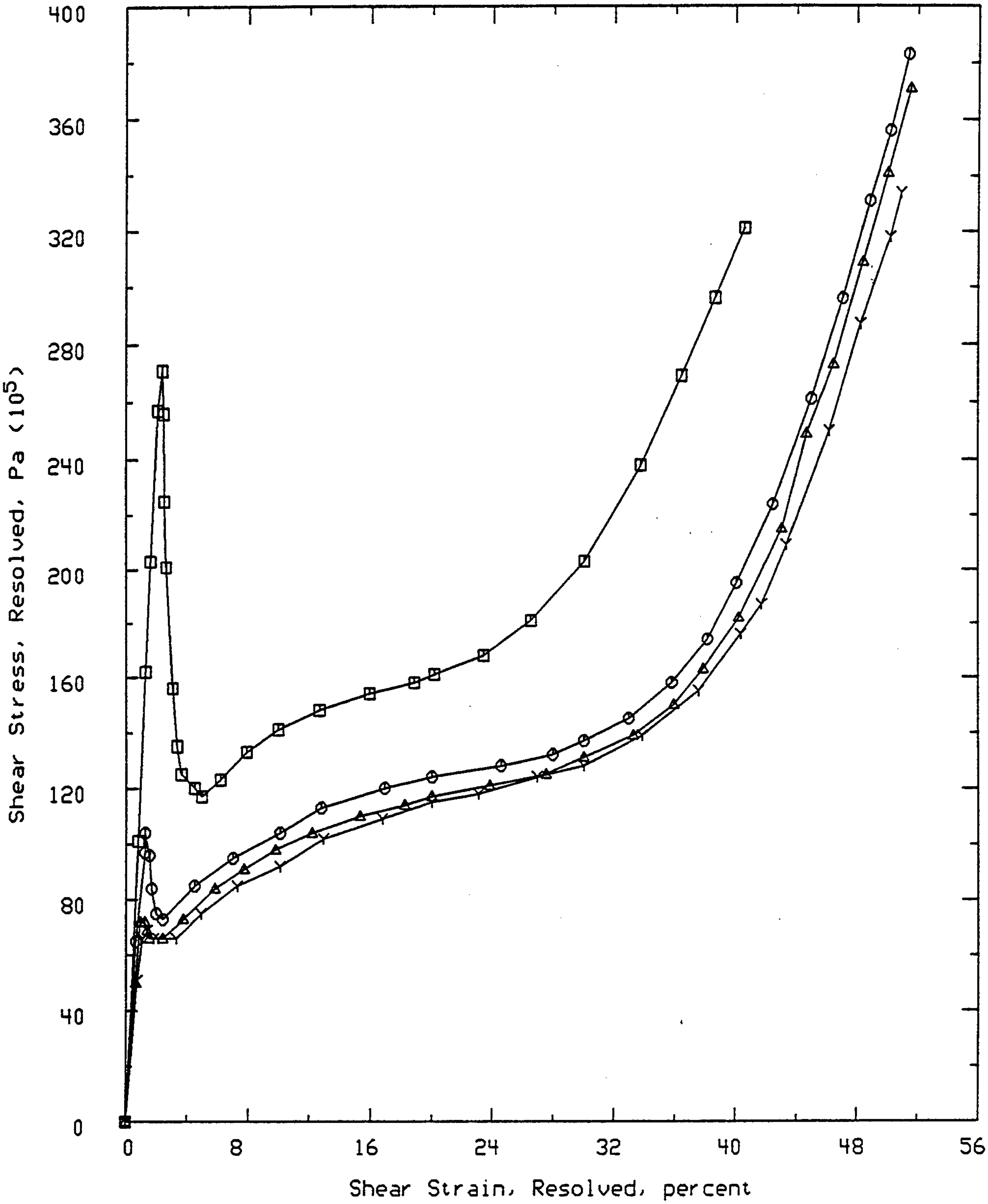

Figure 152 Shear Stress, Resolved of Silicon: P doped

MATERIAL: Silicon, n-type

PROPERTY: Shear Stress, Resolved

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PURDUE UNIVERSITY
DATA SET 153

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Vendor/Producer/Fabricator

POLYROD-grade single crystals obtained from WACKER.

Conditioning History Of Alloys

Heat-Treatment Sequence : Tested in the as-received form

Material Preparation

Crystal Growing Method :

Single crystals obtained by floating-zone technique from POLYROD n-type silicon, dislocation-free.

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Width	4.25	mm
Thickness	4.25	mm

Orientation With Respect To Material : [110] Direction

Additional Identifiers :

Samples stressed along the growth axis.

Additional Properties

Electrical Properties :

Electrical Resistivity	> 5.0	Ω cm
Temperature	298.0	K

Measurement/Evaluation Method

Name/Description :

tests.

Shear Response Under Compressive Loading

High-temperature apparatus mounted to Instron machine.

Tests done under reformed gas.

Shear properties derived from measured data.

Parameters-Codified :

Shear Strain Rate, Resolved : 6.0e-06 s[-1]

Measured/Evaluated Properties

X	: Compressive Strain, True	%
Y	: Shear Stress, Resolved	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
0.000e+00	1.400e+06	1.023e+03
1.200e-01	1.050e+07	1.023e+03
2.500e-01	2.000e+07	1.023e+03
3.000e-01	2.090e+07	1.023e+03
3.000e-01	2.160e+07	1.023e+03
3.300e-01	2.070e+07	1.023e+03
3.900e-01	2.000e+07	1.023e+03
5.900e-01	1.530e+07	1.023e+03
6.700e-01	1.340e+07	1.023e+03
7.300e-01	1.250e+07	1.023e+03
8.500e-01	1.210e+07	1.023e+03
1.020e+00	1.210e+07	1.023e+03
1.510e+00	1.480e+07	1.023e+03
2.060e+00	1.780e+07	1.023e+03
2.560e+00	2.040e+07	1.023e+03
3.220e+00	2.360e+07	1.023e+03
4.010e+00	2.770e+07	1.023e+03
4.820e+00	3.140e+07	1.023e+03
0.000e+00	1.400e+06	1.123e+03
9.000e-02	6.300e+06	1.123e+03
1.200e-01	7.700e+06	1.123e+03
1.800e-01	8.100e+06	1.123e+03
2.400e-01	8.100e+06	1.123e+03
2.900e-01	6.700e+06	1.123e+03
3.800e-01	6.000e+06	1.123e+03
4.700e-01	5.600e+06	1.123e+03
5.800e-01	5.600e+06	1.123e+03
7.800e-01	5.800e+06	1.123e+03
1.250e+00	6.900e+06	1.123e+03
1.830e+00	8.500e+06	1.123e+03
2.700e+00	1.060e+07	1.123e+03
3.040e+00	1.150e+07	1.123e+03
3.590e+00	1.310e+07	1.123e+03
4.170e+00	1.490e+07	1.123e+03
4.780e+00	1.700e+07	1.123e+03
5.390e+00	1.900e+07	1.123e+03
5.940e+00	2.160e+07	1.123e+03
0.000e+00	4.000e+06	1.223e+03
0.000e+00	4.200e+06	1.223e+03
1.800e-01	3.900e+06	1.223e+03
3.500e-01	3.900e+06	1.223e+03
7.300e-01	4.200e+06	1.223e+03

1.250e+00	5.300e+06	1.223e+03
1.740e+00	6.200e+06	1.223e+03
2.230e+00	7.300e+06	1.223e+03
2.980e+00	9.400e+06	1.223e+03
3.420e+00	1.170e+07	1.223e+03
3.910e+00	1.400e+07	1.223e+03
4.490e+00	1.650e+07	1.223e+03
5.100e+00	1.910e+07	1.223e+03
5.420e+00	2.050e+07	1.223e+03
5.710e+00	2.180e+07	1.223e+03
5.940e+00	2.230e+07	1.223e+03
0.000e+00	3.300e+06	1.323e+03
2.900e-01	4.400e+06	1.323e+03
5.200e-01	5.300e+06	1.323e+03
8.700e-01	5.500e+06	1.323e+03
1.070e+00	6.000e+06	1.323e+03
1.420e+00	6.400e+06	1.323e+03
1.860e+00	7.600e+06	1.323e+03
2.350e+00	9.200e+06	1.323e+03
2.810e+00	1.060e+07	1.323e+03
3.040e+00	1.150e+07	1.323e+03
3.540e+00	1.360e+07	1.323e+03
3.940e+00	1.490e+07	1.323e+03
4.350e+00	1.610e+07	1.323e+03
4.840e+00	1.700e+07	1.323e+03
5.480e+00	1.810e+07	1.323e+03
5.910e+00	1.880e+07	1.323e+03
0.000e+00	2.000e+05	1.423e+03
2.000e-02	1.400e+06	1.423e+03
1.200e-01	1.400e+06	1.423e+03
4.100e-01	2.100e+06	1.423e+03
6.700e-01	2.500e+06	1.423e+03
8.700e-01	3.000e+06	1.423e+03
1.100e+00	3.900e+06	1.423e+03
1.480e+00	5.300e+06	1.423e+03
1.910e+00	6.900e+06	1.423e+03
2.310e+00	7.600e+06	1.423e+03
3.040e+00	8.700e+06	1.423e+03
3.480e+00	9.400e+06	1.423e+03
3.940e+00	9.800e+06	1.423e+03
4.290e+00	1.030e+07	1.423e+03

Comments on Data

Data was digitized from Figure 5.

A stress peak is observed at T<1223 K and a stage of easy glide seems to be present, with a slightly higher hardening rate.

Reference

MECHANICAL BEHAVIOR OF POLYCRYSTALS AND SINGLE CRYSTALS OF SILICON.
Omri, M. Michel, J. P. Tete, C.
George, A.
STRENGTH OF METALS AND ALLOYS, VOL. 1, PROC. INT. CONF., ICSMA 7, 1985
1, 75-80, 1986.
(Edited by H. J. McQueen, J. P. Bailon,
J. I. Dickson, J. J. Jonas and M. G. Akben; Pergamon
Press: Elmsford, New York)

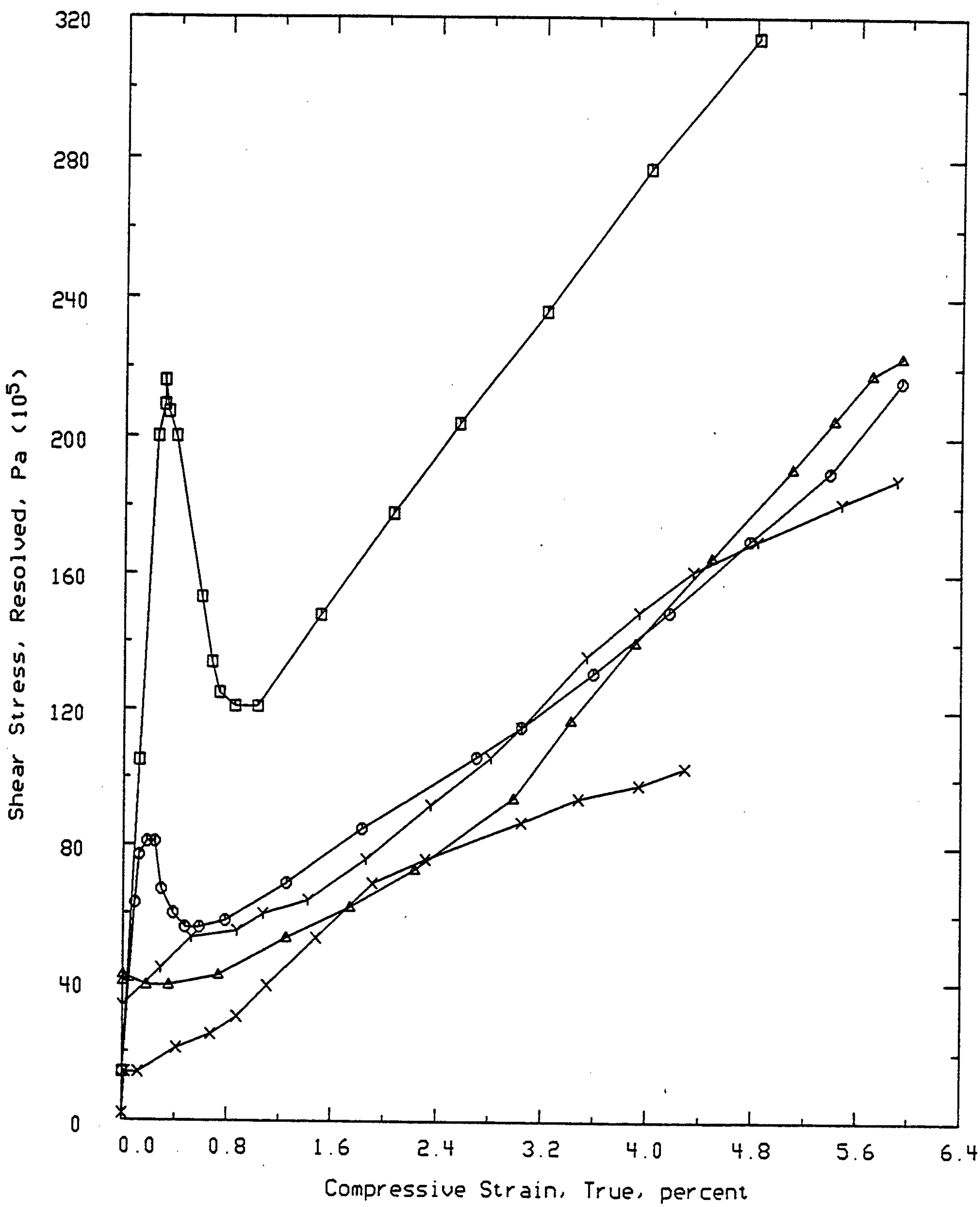

Figure 153 Shear Stress, Resolved of Silicon, n-type

MATERIAL: Silicon, n-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Stress, Resolved	DATA SET 154

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Vendor/Producer/Fabricator

POLYROD-grade single crystals obtained from WACKER.

Conditioning History Of Alloys

Heat-Treatment Sequence : Tested in the as-received form

Material Preparation

Crystal Growing Method :

Single crystals obtained by floating-zone technique from POLYROD n-type silicon, dislocation-free.

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Width	4.25	mm
Thickness	4.25	mm

Orientation With Respect To Material : [100] Direction

Additional Identifiers :

Samples stressed along the growth axis.

Additional Properties

Electrical Properties :

Electrical Resistivity	> 5.0	Ω cm
Temperature	298.0	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading
High-temperature apparatus mounted to Instron machine.
Tests done under reformed gas.
Shear properties derived from measured data.

Parameters-Codified :

Shear Strain Rate, Resolved : 6.0e-06 s[-1]

Measured/Evaluated Properties

X	: Compressive Strain, True	%
Y	: Shear Stress, Resolved	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
0.000e+00	3.000e+06	1.023e+03
3.000e-02	1.000e+07	1.023e+03
9.000e-02	1.770e+07	1.023e+03
1.500e-01	1.790e+07	1.023e+03
2.100e-01	1.770e+07	1.023e+03
2.900e-01	1.600e+07	1.023e+03
4.100e-01	1.510e+07	1.023e+03
4.700e-01	1.490e+07	1.023e+03
5.200e-01	1.490e+07	1.023e+03
6.100e-01	1.530e+07	1.023e+03
8.100e-01	1.810e+07	1.023e+03
9.900e-01	2.000e+07	1.023e+03
1.310e+00	2.300e+07	1.023e+03
1.710e+00	2.580e+07	1.023e+03
0.000e+00	3.000e+06	1.123e+03
1.200e-01	6.000e+06	1.123e+03
3.500e-01	8.100e+06	1.123e+03
6.400e-01	1.000e+07	1.123e+03
1.250e+00	1.350e+07	1.123e+03
1.770e+00	1.620e+07	1.123e+03
2.170e+00	1.830e+07	1.123e+03
2.490e+00	2.040e+07	1.123e+03
3.070e+00	2.370e+07	1.123e+03
3.650e+00	2.710e+07	1.123e+03
4.260e+00	3.110e+07	1.123e+03
0.000e+00	3.000e+06	1.323e+03
1.100e-01	5.800e+06	1.323e+03
2.100e-01	7.440e+06	1.323e+03
3.300e-01	9.450e+06	1.323e+03
4.800e-01	1.100e+07	1.323e+03
6.600e-01	1.250e+07	1.323e+03
8.800e-01	1.390e+07	1.323e+03
1.100e+00	1.500e+07	1.323e+03
1.340e+00	1.590e+07	1.323e+03
1.650e+00	1.670e+07	1.323e+03
2.010e+00	1.750e+07	1.323e+03
2.560e+00	1.810e+07	1.323e+03
3.420e+00	1.900e+07	1.323e+03
3.990e+00	1.930e+07	1.323e+03
4.590e+00	1.940e+07	1.323e+03
5.590e+00	1.980e+07	1.323e+03
0.000e+00	3.000e+06	1.423e+03

6.000e-02	5.100e+06	1.423e+03
4.000e-01	7.000e+06	1.423e+03
7.000e-01	7.900e+06	1.423e+03
1.270e+00	8.300e+06	1.423e+03
1.970e+00	9.000e+06	1.423e+03
3.040e+00	9.200e+06	1.423e+03
4.220e+00	9.700e+06	1.423e+03

Comments on Data

Data was digitized from Figure 6.
A stress peak is observed at T<1223 K and a stage of easy glide seems to be present, with a slightly higher hardening rate.

Reference

MECHANICAL BEHAVIOR OF POLYCRYSTALS AND SINGLE CRYSTALS OF SILICON.
Omri, M. Michel, J. P. Tete, C.
George, A.
STRENGTH OF METALS AND ALLOYS, VOL. 1, PROC. INT. CONF., ICSMA 7, 1985
1, 75-80, 1986.
(Edited by H. J. McQueen, J. P. Bailon,
J. I. Dickson, J. J. Jonas and M. G. Akben; Pergamon
Press: Elmsford, New York)

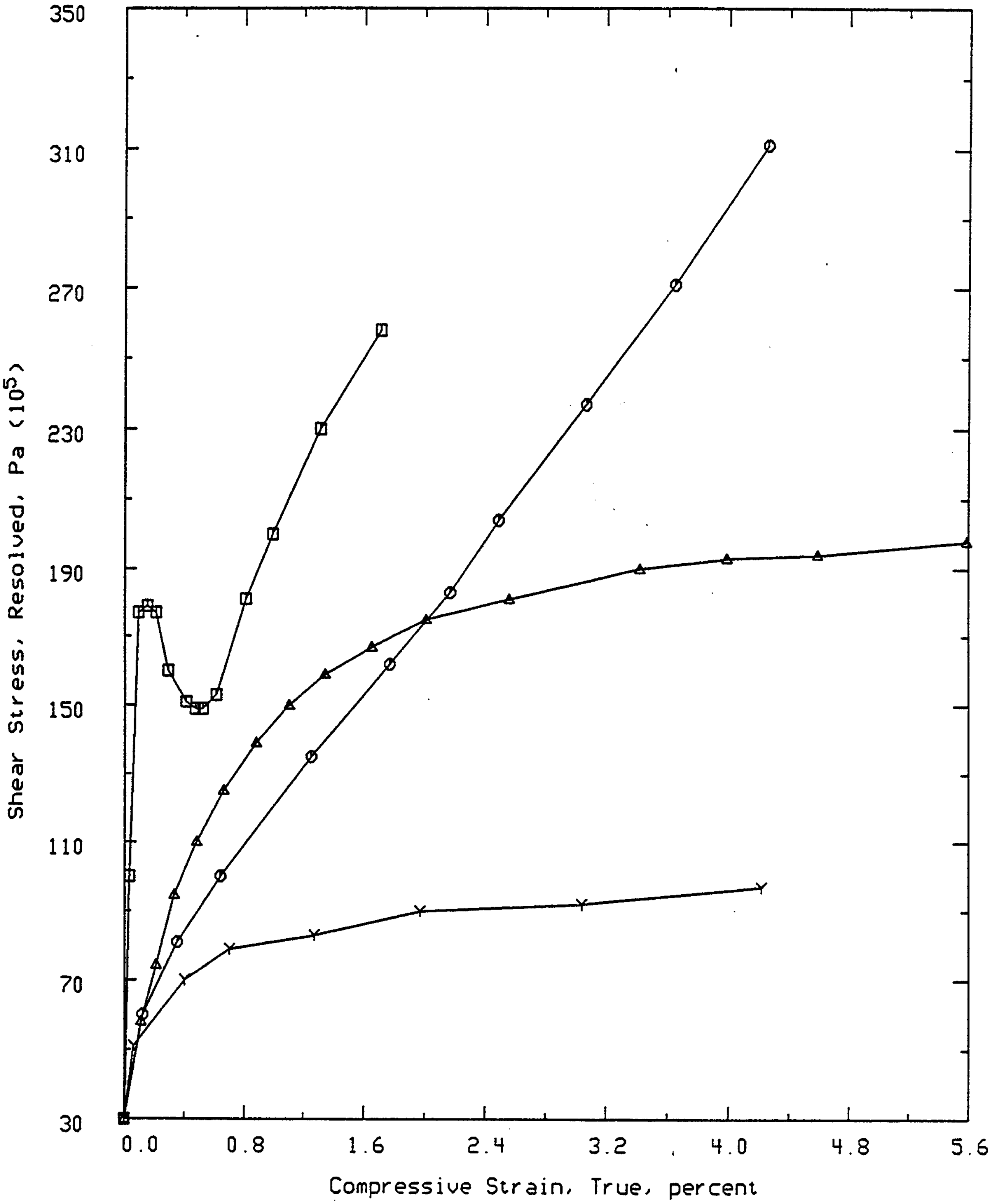

Figure 154 Shear Stress, Resolved of Silicon, n-type

MATERIAL: Silicon, n-type

PROPERTY: Shear Stress, Resolved

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 155

****

Vendor/Producer/Fabricator

Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation

Crystal Growing Method :
Float-zone technique
Crystal grown in a high purity argon gas atmosphere.
Descriptors-Textual :
Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	460.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Shear Response Under Tensile Loading
Parameters-Textual :
Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.
Parameters-Codified :
Temperature : 1073. K
Strain Rate : 1.2e-04 s[-1]

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment
Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X : Shear Strain, Resolved	fraction
Y : Shear Stress, Resolved	Pa
Z1 : Dislocation Density	m^{-2}
Z2 : Strain Rate	s^{-1}

Z3 : Temperature K

Data Points :

X	Y	Z1	Z2	Z3
0.000e+00	0.000e+00	2.000e+08	1.200e-04	1.073e+03
9.000e-03	1.020e+07	2.000e+08	1.200e-04	1.073e+03
1.600e-02	1.600e+07	2.000e+08	1.200e-04	1.073e+03
2.100e-02	2.000e+07	2.000e+08	1.200e-04	1.073e+03
2.200e-02	2.280e+07	2.000e+08	1.200e-04	1.073e+03
2.500e-02	2.310e+07	2.000e+08	1.200e-04	1.073e+03
2.600e-02	2.220e+07	2.000e+08	1.200e-04	1.073e+03
2.700e-02	2.000e+07	2.000e+08	1.200e-04	1.073e+03
2.800e-02	1.750e+07	2.000e+08	1.200e-04	1.073e+03
3.100e-02	1.510e+07	2.000e+08	1.200e-04	1.073e+03
3.400e-02	1.350e+07	2.000e+08	1.200e-04	1.073e+03
3.700e-02	1.260e+07	2.000e+08	1.200e-04	1.073e+03
4.700e-02	1.260e+07	2.000e+08	1.200e-04	1.073e+03
5.300e-02	1.230e+07	2.000e+08	1.200e-04	1.073e+03
5.900e-02	1.260e+07	2.000e+08	1.200e-04	1.073e+03
6.500e-02	1.320e+07	2.000e+08	1.200e-04	1.073e+03
7.400e-02	1.350e+07	2.000e+08	1.200e-04	1.073e+03
8.100e-02	1.410e+07	2.000e+08	1.200e-04	1.073e+03
9.300e-02	1.480e+07	2.000e+08	1.200e-04	1.073e+03
1.020e-01	1.540e+07	2.000e+08	1.200e-04	1.073e+03
1.120e-01	1.600e+07	2.000e+08	1.200e-04	1.073e+03
1.210e-01	1.660e+07	2.000e+08	1.200e-04	1.073e+03
1.300e-01	1.660e+07	2.000e+08	1.200e-04	1.073e+03
1.430e-01	1.720e+07	2.000e+08	1.200e-04	1.073e+03
1.550e-01	1.820e+07	2.000e+08	1.200e-04	1.073e+03
1.710e-01	1.850e+07	2.000e+08	1.200e-04	1.073e+03
2.020e-01	1.970e+07	2.000e+08	1.200e-04	1.073e+03
2.510e-01	2.120e+07	2.000e+08	1.200e-04	1.073e+03
3.010e-01	2.250e+07	2.000e+08	1.200e-04	1.073e+03
3.540e-01	2.370e+07	2.000e+08	1.200e-04	1.073e+03
4.000e-01	2.500e+07	2.000e+08	1.200e-04	1.073e+03
4.250e-01	2.550e+07	2.000e+08	1.200e-04	1.073e+03
4.500e-01	2.620e+07	2.000e+08	1.200e-04	1.073e+03
4.740e-01	2.740e+07	2.000e+08	1.200e-04	1.073e+03
5.020e-01	2.860e+07	2.000e+08	1.200e-04	1.073e+03
6.000e-03	0.000e+00	2.000e+09	1.200e-04	1.073e+03
1.200e-02	6.200e+06	2.000e+09	1.200e-04	1.073e+03
2.200e-02	1.010e+07	2.000e+09	1.200e-04	1.073e+03
2.800e-02	1.480e+07	2.000e+09	1.200e-04	1.073e+03
3.400e-02	1.540e+07	2.000e+09	1.200e-04	1.073e+03

3.500e-02	1.510e+07	2.000e+09	1.200e-04	1.073e+03
3.700e-02	1.350e+07	2.000e+09	1.200e-04	1.073e+03
4.000e-02	1.260e+07	2.000e+09	1.200e-04	1.073e+03
4.100e-02	1.200e+07	2.000e+09	1.200e-04	1.073e+03
4.700e-02	1.170e+07	2.000e+09	1.200e-04	1.073e+03
7.400e-02	1.260e+07	2.000e+09	1.200e-04	1.073e+03
8.700e-02	1.320e+07	2.000e+09	1.200e-04	1.073e+03
9.900e-02	1.390e+07	2.000e+09	1.200e-04	1.073e+03
1.120e-01	1.420e+07	2.000e+09	1.200e-04	1.073e+03
1.210e-01	1.450e+07	2.000e+09	1.200e-04	1.073e+03
1.300e-01	1.480e+07	2.000e+09	1.200e-04	1.073e+03
1.430e-01	1.540e+07	2.000e+09	1.200e-04	1.073e+03
1.710e-01	1.630e+07	2.000e+09	1.200e-04	1.073e+03
2.020e-01	1.750e+07	2.000e+09	1.200e-04	1.073e+03
2.260e-01	1.820e+07	2.000e+09	1.200e-04	1.073e+03
2.510e-01	1.880e+07	2.000e+09	1.200e-04	1.073e+03
2.790e-01	1.940e+07	2.000e+09	1.200e-04	1.073e+03
3.010e-01	1.970e+07	2.000e+09	1.200e-04	1.073e+03
3.500e-01	2.030e+07	2.000e+09	1.200e-04	1.073e+03
3.780e-01	2.060e+07	2.000e+09	1.200e-04	1.073e+03
4.030e-01	2.060e+07	2.000e+09	1.200e-04	1.073e+03
4.310e-01	2.120e+07	2.000e+09	1.200e-04	1.073e+03
4.530e-01	2.190e+07	2.000e+09	1.200e-04	1.073e+03
4.650e-01	2.310e+07	2.000e+09	1.200e-04	1.073e+03
5.020e-01	2.460e+07	2.000e+09	1.200e-04	1.073e+03

2.200e-02	0.000e+00	9.000e+09	1.200e-04	1.073e+03
3.400e-02	5.800e+06	9.000e+09	1.200e-04	1.073e+03
4.000e-02	9.200e+06	9.000e+09	1.200e-04	1.073e+03
4.300e-02	9.800e+06	9.000e+09	1.200e-04	1.073e+03
4.700e-02	9.500e+06	9.000e+09	1.200e-04	1.073e+03
7.400e-02	1.020e+07	9.000e+09	1.200e-04	1.073e+03
7.800e-02	1.080e+07	9.000e+09	1.200e-04	1.073e+03
8.700e-02	1.140e+07	9.000e+09	1.200e-04	1.073e+03
9.900e-02	1.200e+07	9.000e+09	1.200e-04	1.073e+03
1.120e-01	1.260e+07	9.000e+09	1.200e-04	1.073e+03
1.180e-01	1.290e+07	9.000e+09	1.200e-04	1.073e+03
1.300e-01	1.320e+07	9.000e+09	1.200e-04	1.073e+03
1.430e-01	1.390e+07	9.000e+09	1.200e-04	1.073e+03
1.550e-01	1.450e+07	9.000e+09	1.200e-04	1.073e+03
1.670e-01	1.510e+07	9.000e+09	1.200e-04	1.073e+03
1.830e-01	1.600e+07	9.000e+09	1.200e-04	1.073e+03
1.980e-01	1.660e+07	9.000e+09	1.200e-04	1.073e+03
2.260e-01	1.750e+07	9.000e+09	1.200e-04	1.073e+03
2.510e-01	1.850e+07	9.000e+09	1.200e-04	1.073e+03
2.760e-01	1.850e+07	9.000e+09	1.200e-04	1.073e+03

3.040e-01	1.910e+07	9.000e+09	1.200e-04	1.073e+03
3.260e-01	1.970e+07	9.000e+09	1.200e-04	1.073e+03
3.500e-01	1.970e+07	9.000e+09	1.200e-04	1.073e+03
4.000e-01	2.000e+07	9.000e+09	1.200e-04	1.073e+03
4.250e-01	2.000e+07	9.000e+09	1.200e-04	1.073e+03
4.500e-01	2.060e+07	9.000e+09	1.200e-04	1.073e+03
4.740e-01	2.090e+07	9.000e+09	1.200e-04	1.073e+03
4.990e-01	2.150e+07	9.000e+09	1.200e-04	1.073e+03

2.800e-02	0.000e+00	1.700e+10	1.200e-04	1.073e+03
3.700e-02	5.500e+06	1.700e+10	1.200e-04	1.073e+03
5.000e-02	9.200e+06	1.700e+10	1.200e-04	1.073e+03
6.200e-02	9.500e+06	1.700e+10	1.200e-04	1.073e+03
7.400e-02	1.020e+07	1.700e+10	1.200e-04	1.073e+03
8.700e-02	1.080e+07	1.700e+10	1.200e-04	1.073e+03
9.900e-02	1.140e+07	1.700e+10	1.200e-04	1.073e+03
1.120e-01	1.200e+07	1.700e+10	1.200e-04	1.073e+03
1.180e-01	1.260e+07	1.700e+10	1.200e-04	1.073e+03
1.300e-01	1.320e+07	1.700e+10	1.200e-04	1.073e+03
1.430e-01	1.390e+07	1.700e+10	1.200e-04	1.073e+03
1.550e-01	1.450e+07	1.700e+10	1.200e-04	1.073e+03
1.670e-01	1.510e+07	1.700e+10	1.200e-04	1.073e+03
1.860e-01	1.600e+07	1.700e+10	1.200e-04	1.073e+03
2.020e-01	1.660e+07	1.700e+10	1.200e-04	1.073e+03
2.260e-01	1.750e+07	1.700e+10	1.200e-04	1.073e+03
2.510e-01	1.820e+07	1.700e+10	1.200e-04	1.073e+03
2.820e-01	1.880e+07	1.700e+10	1.200e-04	1.073e+03
3.010e-01	1.940e+07	1.700e+10	1.200e-04	1.073e+03
3.260e-01	2.000e+07	1.700e+10	1.200e-04	1.073e+03
3.540e-01	2.030e+07	1.700e+10	1.200e-04	1.073e+03
3.940e-01	2.060e+07	1.700e+10	1.200e-04	1.073e+03
4.030e-01	2.090e+07	1.700e+10	1.200e-04	1.073e+03
4.220e-01	2.150e+07	1.700e+10	1.200e-04	1.073e+03
4.470e-01	2.220e+07	1.700e+10	1.200e-04	1.073e+03

Comments on Data

For specimens showing no yield point phenomenon, the strain at lower yield point is taken as that of intersection of extensions of elastic region and of stress-strain curve. Yield behavior strongly affected by initial density of dislocations.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A

50, 685-93, 1978.

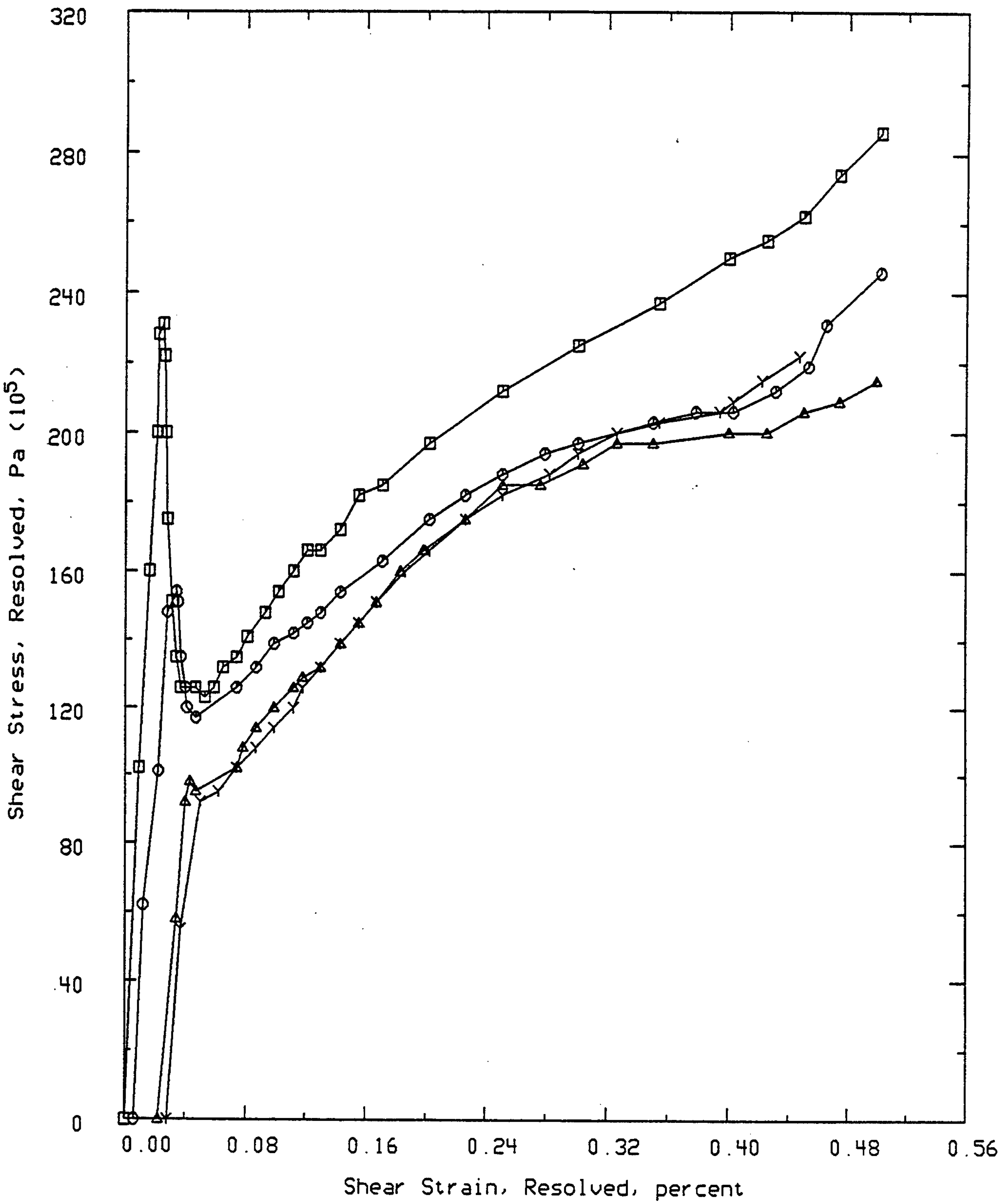

Figure 155 Shear Stress, Resolved of Silicon, n-type

MATERIAL: Silicon, n-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Stress, Resolved	DATA SET 156

****

Vendor/Producer/Fabricator

Wacker

Material Preparation

Crystal Growing Method :

Float-zone grown, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

{111} and {541} side faces cut with a diamond saw and diamond polished (1/4 micron)

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Thickness	4.25	mm
Width	4.25	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Specimen oriented to obtain a single slip deformation along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	>5.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

High-temperature compression stage apparatus mounted on an Instron machine. A continuous flow of forming gas (10 pct. H(2), 90 pct. N(2)) maintained during each test. Curves of resolved shear stress - strain derived from the recorded data.

Parameters-Codified :

Shear Strain Rate, Resolved : 2.e-05 s[-1]

Measured/Evaluated Properties

X	: Shear Strain, Resolved	%
Y	: Shear Stress, Resolved	Pa
Z1	: Temperature	K

Z2 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1	Z2
3.000e-01	8.500e+06	1.023e+03	2.000e-05
3.050e-01	1.000e+07	1.023e+03	2.000e-05
3.100e-01	1.390e+07	1.023e+03	2.000e-05
4.600e-01	1.660e+07	1.023e+03	2.000e-05
7.500e-01	1.680e+07	1.023e+03	2.000e-05
7.500e-01	1.660e+07	1.023e+03	2.000e-05
2.030e+00	1.320e+07	1.023e+03	2.000e-05
3.030e+00	1.000e+07	1.023e+03	2.000e-05
3.600e+00	9.100e+06	1.023e+03	2.000e-05
3.740e+00	8.800e+06	1.023e+03	2.000e-05
4.170e+00	8.700e+06	1.023e+03	2.000e-05
4.460e+00	8.800e+06	1.023e+03	2.000e-05
5.750e+00	1.000e+07	1.023e+03	2.000e-05
8.050e+00	1.150e+07	1.023e+03	2.000e-05
1.078e+01	1.280e+07	1.023e+03	2.000e-05
1.351e+01	1.400e+07	1.023e+03	2.000e-05
1.795e+01	1.540e+07	1.023e+03	2.000e-05
7.300e-01	6.600e+06	1.073e+03	2.000e-05
8.800e-01	8.300e+06	1.073e+03	2.000e-05
1.020e+00	8.400e+06	1.073e+03	2.000e-05
1.300e+00	8.300e+06	1.073e+03	2.000e-05
2.440e+00	5.500e+06	1.073e+03	2.000e-05
2.730e+00	5.100e+06	1.073e+03	2.000e-05
3.160e+00	4.900e+06	1.073e+03	2.000e-05
3.450e+00	4.900e+06	1.073e+03	2.000e-05
4.020e+00	5.100e+06	1.073e+03	2.000e-05
5.310e+00	5.700e+06	1.073e+03	2.000e-05
6.460e+00	6.400e+06	1.073e+03	2.000e-05
8.330e+00	7.000e+06	1.073e+03	2.000e-05
1.005e+01	7.700e+06	1.073e+03	2.000e-05
1.206e+01	8.100e+06	1.073e+03	2.000e-05
1.378e+01	8.600e+06	1.073e+03	2.000e-05
1.579e+01	9.000e+06	1.073e+03	2.000e-05
1.780e+01	9.400e+06	1.073e+03	2.000e-05
1.995e+01	9.700e+06	1.073e+03	2.000e-05
2.181e+01	1.010e+07	1.073e+03	2.000e-05
2.439e+01	1.040e+07	1.073e+03	2.000e-05
2.683e+01	1.080e+07	1.073e+03	2.000e-05
2.999e+01	1.160e+07	1.073e+03	2.000e-05
3.214e+01	1.220e+07	1.073e+03	2.000e-05

3.415e+01	1.280e+07	1.073e+03	2.000e-05
3.616e+01	1.350e+07	1.073e+03	2.000e-05
3.817e+01	1.450e+07	1.073e+03	2.000e-05
4.018e+01	1.550e+07	1.073e+03	2.000e-05
4.132e+01	1.630e+07	1.073e+03	2.000e-05
4.262e+01	1.710e+07	1.073e+03	2.000e-05
1.500e-01	4.200e+06	1.123e+03	2.000e-05
3.000e-01	6.100e+06	1.123e+03	2.000e-05
5.800e-01	6.500e+06	1.123e+03	2.000e-05
8.700e-01	6.300e+06	1.123e+03	2.000e-05
1.150e+00	5.300e+06	1.123e+03	2.000e-05
1.720e+00	4.000e+06	1.123e+03	2.000e-05
2.010e+00	3.700e+06	1.123e+03	2.000e-05
2.580e+00	3.300e+06	1.123e+03	2.000e-05
3.010e+00	3.100e+06	1.123e+03	2.000e-05
3.870e+00	3.100e+06	1.123e+03	2.000e-05
4.730e+00	3.300e+06	1.123e+03	2.000e-05
6.170e+00	3.600e+06	1.123e+03	2.000e-05
7.600e+00	4.000e+06	1.123e+03	2.000e-05
8.890e+00	4.400e+06	1.123e+03	2.000e-05
9.900e+00	4.700e+06	1.123e+03	2.000e-05
1.205e+01	5.000e+06	1.123e+03	2.000e-05
1.363e+01	5.500e+06	1.123e+03	2.000e-05
1.535e+01	5.700e+06	1.123e+03	2.000e-05
1.765e+01	6.000e+06	1.123e+03	2.000e-05
1.994e+01	6.300e+06	1.123e+03	2.000e-05
2.224e+01	6.600e+06	1.123e+03	2.000e-05
2.410e+01	6.700e+06	1.123e+03	2.000e-05
2.553e+01	6.900e+06	1.123e+03	2.000e-05
2.754e+01	7.200e+06	1.123e+03	2.000e-05
2.898e+01	7.600e+06	1.123e+03	2.000e-05
3.012e+01	8.000e+06	1.123e+03	2.000e-05
3.185e+01	8.400e+06	1.123e+03	2.000e-05
3.342e+01	9.300e+06	1.123e+03	2.000e-05
3.486e+01	1.010e+07	1.123e+03	2.000e-05
3.615e+01	1.110e+07	1.123e+03	2.000e-05
3.845e+01	1.340e+07	1.123e+03	2.000e-05
4.003e+01	1.520e+07	1.123e+03	2.000e-05
4.247e+01	1.780e+07	1.123e+03	2.000e-05
4.406e+01	2.000e+07	1.123e+03	2.000e-05
4.300e-01	3.200e+06	1.173e+03	2.000e-05
4.300e-01	3.900e+06	1.173e+03	2.000e-05
5.800e-01	4.100e+06	1.173e+03	2.000e-05
1.010e+00	4.000e+06	1.173e+03	2.000e-05

1.150e+00	3.500e+06	1.173e+03	2.000e-05
1.720e+00	3.200e+06	1.173e+03	2.000e-05
2.730e+00	2.800e+06	1.173e+03	2.000e-05
3.730e+00	2.700e+06	1.173e+03	2.000e-05
4.880e+00	2.700e+06	1.173e+03	2.000e-05
6.020e+00	2.900e+06	1.173e+03	2.000e-05
7.750e+00	3.200e+06	1.173e+03	2.000e-05
1.004e+01	3.500e+06	1.173e+03	2.000e-05
1.349e+01	4.000e+06	1.173e+03	2.000e-05
1.650e+01	4.400e+06	1.173e+03	2.000e-05
1.994e+01	4.800e+06	1.173e+03	2.000e-05
2.180e+01	5.400e+06	1.173e+03	2.000e-05
2.367e+01	6.200e+06	1.173e+03	2.000e-05
2.625e+01	7.900e+06	1.173e+03	2.000e-05
2.812e+01	9.400e+06	1.173e+03	2.000e-05
3.013e+01	1.140e+07	1.173e+03	2.000e-05
3.186e+01	1.380e+07	1.173e+03	2.000e-05
3.301e+01	1.510e+07	1.173e+03	2.000e-05
3.430e+01	1.650e+07	1.173e+03	2.000e-05
3.545e+01	1.750e+07	1.173e+03	2.000e-05
3.660e+01	1.850e+07	1.173e+03	2.000e-05
3.818e+01	1.970e+07	1.173e+03	2.000e-05
1.400e-01	0.000e+00	1.223e+03	2.000e-05
1.500e-01	1.600e+06	1.223e+03	2.000e-05
4.300e-01	2.900e+06	1.223e+03	2.000e-05
5.800e-01	3.100e+06	1.223e+03	2.000e-05
8.600e-01	3.100e+06	1.223e+03	2.000e-05
1.440e+00	2.800e+06	1.223e+03	2.000e-05
2.150e+00	2.700e+06	1.223e+03	2.000e-05
3.300e+00	2.800e+06	1.223e+03	2.000e-05
5.310e+00	2.900e+06	1.223e+03	2.000e-05
6.880e+00	3.100e+06	1.223e+03	2.000e-05
7.740e+00	3.200e+06	1.223e+03	2.000e-05
1.004e+01	3.200e+06	1.223e+03	2.000e-05
1.305e+01	3.300e+06	1.223e+03	2.000e-05
1.377e+01	3.400e+06	1.223e+03	2.000e-05
1.520e+01	3.600e+06	1.223e+03	2.000e-05
1.764e+01	4.100e+06	1.223e+03	2.000e-05
1.980e+01	4.800e+06	1.223e+03	2.000e-05
2.152e+01	5.700e+06	1.223e+03	2.000e-05
2.209e+01	6.100e+06	1.223e+03	2.000e-05
2.324e+01	7.000e+06	1.223e+03	2.000e-05
2.511e+01	8.500e+06	1.223e+03	2.000e-05
2.683e+01	1.020e+07	1.223e+03	2.000e-05
2.827e+01	1.130e+07	1.223e+03	2.000e-05

2.942e+01	1.210e+07	1.223e+03	2.000e-05
3.028e+01	1.290e+07	1.223e+03	2.000e-05
3.085e+01	1.330e+07	1.223e+03	2.000e-05
3.157e+01	1.400e+07	1.223e+03	2.000e-05

0.000e+00	0.000e+00	1.273e+03	2.000e-05
2.800e-01	1.900e+06	1.273e+03	2.000e-05
4.200e-01	2.600e+06	1.273e+03	2.000e-05
6.400e-01	2.900e+06	1.273e+03	2.000e-05
7.800e-01	3.000e+06	1.273e+03	2.000e-05
1.140e+00	2.900e+06	1.273e+03	2.000e-05
1.500e+00	2.800e+06	1.273e+03	2.000e-05
1.790e+00	2.800e+06	1.273e+03	2.000e-05
2.220e+00	2.900e+06	1.273e+03	2.000e-05
3.450e+00	2.900e+06	1.273e+03	2.000e-05
4.460e+00	3.000e+06	1.273e+03	2.000e-05
5.470e+00	3.200e+06	1.273e+03	2.000e-05
6.700e+00	3.300e+06	1.273e+03	2.000e-05
8.070e+00	3.400e+06	1.273e+03	2.000e-05
9.950e+00	3.600e+06	1.273e+03	2.000e-05
1.161e+01	3.700e+06	1.273e+03	2.000e-05
1.306e+01	4.000e+06	1.273e+03	2.000e-05
1.486e+01	4.500e+06	1.273e+03	2.000e-05
1.674e+01	5.100e+06	1.273e+03	2.000e-05
1.825e+01	5.700e+06	1.273e+03	2.000e-05
2.005e+01	6.500e+06	1.273e+03	2.000e-05
2.121e+01	7.200e+06	1.273e+03	2.000e-05
2.243e+01	8.000e+06	1.273e+03	2.000e-05
2.380e+01	9.200e+06	1.273e+03	2.000e-05
2.524e+01	1.020e+07	1.273e+03	2.000e-05
2.719e+01	1.150e+07	1.273e+03	2.000e-05

0.000e+00	0.000e+00	1.323e+03	2.000e-05
2.800e-01	1.900e+06	1.323e+03	2.000e-05
3.500e-01	2.400e+06	1.323e+03	2.000e-05
4.900e-01	2.500e+06	1.323e+03	2.000e-05
8.500e-01	2.700e+06	1.323e+03	2.000e-05
1.220e+00	2.500e+06	1.323e+03	2.000e-05
1.430e+00	2.500e+06	1.323e+03	2.000e-05
1.860e+00	2.600e+06	1.323e+03	2.000e-05
2.950e+00	2.700e+06	1.323e+03	2.000e-05
4.460e+00	3.100e+06	1.323e+03	2.000e-05
5.470e+00	3.200e+06	1.323e+03	2.000e-05
6.700e+00	3.300e+06	1.323e+03	2.000e-05
8.000e+00	3.400e+06	1.323e+03	2.000e-05
9.150e+00	3.700e+06	1.323e+03	2.000e-05

9.950e+00	4.000e+06	1.323e+03	2.000e-05
1.111e+01	4.500e+06	1.323e+03	2.000e-05
1.204e+01	5.000e+06	1.323e+03	2.000e-05
1.312e+01	5.600e+06	1.323e+03	2.000e-05
1.420e+01	6.400e+06	1.323e+03	2.000e-05
1.492e+01	7.100e+06	1.323e+03	2.000e-05
1.572e+01	7.700e+06	1.323e+03	2.000e-05
1.658e+01	8.200e+06	1.323e+03	2.000e-05
1.759e+01	8.800e+06	1.323e+03	2.000e-05
1.882e+01	9.300e+06	1.323e+03	2.000e-05
2.011e+01	9.700e+06	1.323e+03	2.000e-05
2.120e+01	1.020e+07	1.323e+03	2.000e-05
2.264e+01	1.050e+07	1.323e+03	2.000e-05
2.459e+01	1.090e+07	1.323e+03	2.000e-05
0.000e+00	0.000e+00	1.373e+03	2.000e-05
6.000e-02	1.200e+06	1.373e+03	2.000e-05
2.100e-01	1.700e+06	1.373e+03	2.000e-05
5.000e-01	1.800e+06	1.373e+03	2.000e-05
6.400e-01	1.700e+06	1.373e+03	2.000e-05
1.000e+00	1.700e+06	1.373e+03	2.000e-05
1.510e+00	1.700e+06	1.373e+03	2.000e-05
2.160e+00	1.900e+06	1.373e+03	2.000e-05
2.880e+00	2.000e+06	1.373e+03	2.000e-05
3.960e+00	2.100e+06	1.373e+03	2.000e-05
5.110e+00	2.400e+06	1.373e+03	2.000e-05
6.270e+00	2.900e+06	1.373e+03	2.000e-05
7.420e+00	3.900e+06	1.373e+03	2.000e-05
7.930e+00	4.500e+06	1.373e+03	2.000e-05
8.640e+00	5.000e+06	1.373e+03	2.000e-05
9.290e+00	5.600e+06	1.373e+03	2.000e-05
1.002e+01	5.900e+06	1.373e+03	2.000e-05
1.103e+01	6.300e+06	1.373e+03	2.000e-05
1.233e+01	6.700e+06	1.373e+03	2.000e-05
1.334e+01	7.100e+06	1.373e+03	2.000e-05
1.471e+01	7.300e+06	1.373e+03	2.000e-05
0.000e+00	0.000e+00	1.473e+03	2.000e-05
7.000e-02	2.000e+05	1.473e+03	2.000e-05
2.100e-01	3.000e+05	1.473e+03	2.000e-05
5.000e-01	2.000e+05	1.473e+03	2.000e-05
1.080e+00	2.000e+05	1.473e+03	2.000e-05
1.510e+00	4.000e+05	1.473e+03	2.000e-05
2.160e+00	6.000e+05	1.473e+03	2.000e-05
2.810e+00	9.000e+05	1.473e+03	2.000e-05
3.380e+00	1.300e+06	1.473e+03	2.000e-05

3.820e+00	1.800e+06	1.473e+03	2.000e-05
4.100e+00	2.000e+06	1.473e+03	2.000e-05
4.680e+00	2.300e+06	1.473e+03	2.000e-05
5.550e+00	2.500e+06	1.473e+03	2.000e-05
6.780e+00	2.700e+06	1.473e+03	2.000e-05
8.290e+00	3.000e+06	1.473e+03	2.000e-05
1.000e+01	3.200e+06	1.473e+03	2.000e-05
1.169e+01	3.500e+06	1.473e+03	2.000e-05
1.407e+01	3.800e+06	1.473e+03	2.000e-05
1.602e+01	4.100e+06	1.473e+03	2.000e-05
1.789e+01	4.300e+06	1.473e+03	2.000e-05
1.977e+01	4.800e+06	1.473e+03	2.000e-05

0.000e+00	0.000e+00	1.623e+03	2.000e-05
7.000e-02	3.000e+05	1.623e+03	2.000e-05
2.800e-01	4.000e+05	1.623e+03	2.000e-05
1.000e+00	4.000e+05	1.623e+03	2.000e-05
2.160e+00	6.000e+05	1.623e+03	2.000e-05
3.030e+00	7.000e+05	1.623e+03	2.000e-05
3.530e+00	7.000e+05	1.623e+03	2.000e-05
4.690e+00	8.000e+05	1.623e+03	2.000e-05
5.990e+00	9.000e+05	1.623e+03	2.000e-05
6.560e+00	1.000e+06	1.623e+03	2.000e-05
7.280e+00	1.200e+06	1.623e+03	2.000e-05
8.150e+00	1.500e+06	1.623e+03	2.000e-05
9.020e+00	1.800e+06	1.623e+03	2.000e-05
9.660e+00	1.800e+06	1.623e+03	2.000e-05
1.000e+01	1.900e+06	1.623e+03	2.000e-05
1.070e+01	2.000e+06	1.623e+03	2.000e-05
1.140e+01	2.100e+06	1.623e+03	2.000e-05
1.227e+01	2.100e+06	1.623e+03	2.000e-05

Comments on Data

Data read from figures.
The curves exhibit the usual shape, with an initial peak stress followed by the three stages characteristic of f.c.c. crystals.

Reference

ON THE YIELD POINT OF FLOATING-ZONE SILICON SINGLE CRYSTALS. I. YIELD STRESSES AND ACTIVATION PARAMETERS.
Omri, M. Tete, C. Michel, J. P.
George, A.
PHILOS. MAG. A
55 (5), 601-16, 1987.

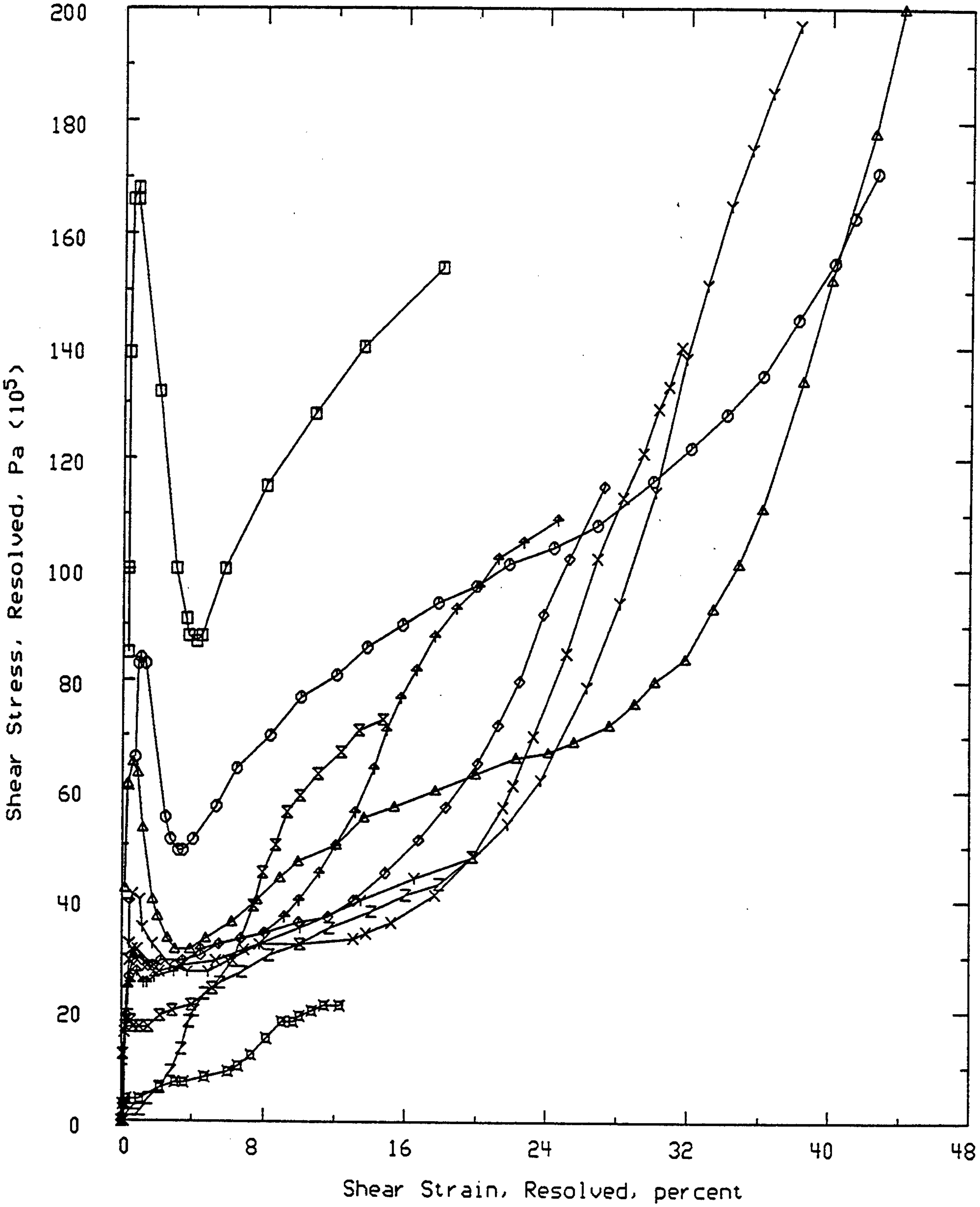

Figure 156 Shear Stress, Resolved of Silicon, n-type

MATERIAL: Silicon, n-type

PROPERTY: Shear Stress, Resolved

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 157

****

Vendor/Producer/Fabricator

Wacker

Material Preparation

Crystal Growing Method :

Float-zone grown, dislocation-free

Descriptors-Textual :

crystal pre-strained to extend temperature range towards lower range

Additional Preparation/Conditioning

Surface Treatment :

{111} and {541} side faces cut with a diamond saw and diamond polished (1/4 micron)

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Thickness	4.25	mm
Width	4.25	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Specimen oriented to obtain a single slip deformation along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	>5.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

High-temperature compression stage apparatus mounted on an Instron machine. A continuous flow of forming gas (10 pct. H(2), 90 pct. N(2)) maintained during each test. Curves of resolved shear stress - strain derived from the recorded data.

Parameters-Codified :

Pre-Strain Rate, Plastic : 7.e-02 pct. (shear)

Shear Strain Rate, Resolved : 2.e-05 s[-1] (pre-straining)

Pre-Strain Temperature : 1323. K

Measured/Evaluated Properties

X : Shear Strain, Resolved		%
Y : Shear Stress, Resolved		Pa
Z1 : Temperature		K
Z2 : Shear Strain Rate, Resolved		s^{-1}

Data Points :

X	Y	Z1	Z2
8.000e-01	4.370e+07	8.180e+02	2.000e-05
8.000e-01	5.020e+07	8.180e+02	2.000e-05
9.400e-01	6.020e+07	8.180e+02	2.000e-05
1.090e+00	6.810e+07	8.180e+02	2.000e-05
1.450e+00	7.530e+07	8.180e+02	2.000e-05
1.740e+00	7.890e+07	8.180e+02	2.000e-05
2.020e+00	8.100e+07	8.180e+02	2.000e-05
2.450e+00	8.180e+07	8.180e+02	2.000e-05
2.740e+00	8.180e+07	8.180e+02	2.000e-05
3.310e+00	7.890e+07	8.180e+02	2.000e-05
4.310e+00	7.310e+07	8.180e+02	2.000e-05
5.520e+00	6.670e+07	8.180e+02	2.000e-05
6.160e+00	6.340e+07	8.180e+02	2.000e-05
6.870e+00	6.050e+07	8.180e+02	2.000e-05
7.730e+00	5.770e+07	8.180e+02	2.000e-05
8.800e+00	5.510e+07	8.180e+02	2.000e-05
9.870e+00	5.370e+07	8.180e+02	2.000e-05
1.045e+01	5.480e+07	8.180e+02	2.000e-05
4.400e-01	3.730e+07	8.280e+02	2.000e-05
5.800e-01	5.090e+07	8.280e+02	2.000e-05
8.000e-01	6.530e+07	8.280e+02	2.000e-05
9.500e-01	7.030e+07	8.280e+02	2.000e-05
1.020e+00	7.240e+07	8.280e+02	2.000e-05
1.380e+00	7.390e+07	8.280e+02	2.000e-05
1.590e+00	7.350e+07	8.280e+02	2.000e-05
2.300e+00	6.990e+07	8.280e+02	2.000e-05
3.590e+00	6.130e+07	8.280e+02	2.000e-05
4.870e+00	5.270e+07	8.280e+02	2.000e-05
5.650e+00	4.870e+07	8.280e+02	2.000e-05
6.370e+00	4.660e+07	8.280e+02	2.000e-05
7.080e+00	4.480e+07	8.280e+02	2.000e-05
7.940e+00	4.370e+07	8.280e+02	2.000e-05
9.150e+00	4.400e+07	8.280e+02	2.000e-05
2.200e-01	3.760e+07	8.480e+02	2.000e-05

3.700e-01	4.300e+07	8.480e+02	2.000e-05
5.100e-01	5.050e+07	8.480e+02	2.000e-05
5.800e-01	5.140e+07	8.480e+02	2.000e-05
9.400e-01	5.160e+07	8.480e+02	2.000e-05
1.230e+00	5.160e+07	8.480e+02	2.000e-05
1.870e+00	4.840e+07	8.480e+02	2.000e-05
2.580e+00	4.410e+07	8.480e+02	2.000e-05
3.150e+00	4.010e+07	8.480e+02	2.000e-05
3.720e+00	3.720e+07	8.480e+02	2.000e-05
4.360e+00	3.510e+07	8.480e+02	2.000e-05
4.940e+00	3.360e+07	8.480e+02	2.000e-05
5.650e+00	3.330e+07	8.480e+02	2.000e-05
6.580e+00	3.330e+07	8.480e+02	2.000e-05
8.790e+00	3.400e+07	8.480e+02	2.000e-05
1.030e+01	3.500e+07	8.480e+02	2.000e-05
1.165e+01	3.610e+07	8.480e+02	2.000e-05
7.500e-03	2.260e+07	8.730e+02	2.000e-05
9.900e-03	2.970e+07	8.730e+02	2.000e-05
8.200e-02	3.260e+07	8.730e+02	2.000e-05
8.200e-02	3.400e+07	8.730e+02	2.000e-05
2.200e-01	3.580e+07	8.730e+02	2.000e-05
4.400e-01	3.620e+07	8.730e+02	2.000e-05
6.500e-01	3.550e+07	8.730e+02	2.000e-05
9.400e-01	3.260e+07	8.730e+02	2.000e-05
1.290e+00	2.970e+07	8.730e+02	2.000e-05
1.650e+00	2.760e+07	8.730e+02	2.000e-05
2.150e+00	2.540e+07	8.730e+02	2.000e-05
2.650e+00	2.470e+07	8.730e+02	2.000e-05
3.080e+00	2.430e+07	8.730e+02	2.000e-05
4.000e+00	2.580e+07	8.730e+02	2.000e-05
4.800e+00	2.680e+07	8.730e+02	2.000e-05
5.720e+00	2.790e+07	8.730e+02	2.000e-05
0.000e+00	1.180e+07	9.230e+02	2.000e-05
2.900e-01	1.500e+07	9.230e+02	2.000e-05
4.300e-01	1.500e+07	9.230e+02	2.000e-05
8.600e-01	1.360e+07	9.230e+02	2.000e-05
1.570e+00	1.290e+07	9.230e+02	2.000e-05
2.360e+00	1.290e+07	9.230e+02	2.000e-05
4.070e+00	1.390e+07	9.230e+02	2.000e-05
5.290e+00	1.500e+07	9.230e+02	2.000e-05
7.140e+00	1.600e+07	9.230e+02	2.000e-05
9.790e+00	1.780e+07	9.230e+02	2.000e-05
1.208e+01	1.920e+07	9.230e+02	2.000e-05
1.472e+01	2.140e+07	9.230e+02	2.000e-05

2.000e-02	6.800e+06	1.023e+03	2.000e-05
1.400e-01	8.200e+06	1.023e+03	2.000e-05
1.400e-01	8.200e+06	1.023e+03	2.000e-05
4.300e-01	7.500e+06	1.023e+03	2.000e-05
7.100e-01	7.500e+06	1.023e+03	2.000e-05
1.140e+00	8.200e+06	1.023e+03	2.000e-05
1.860e+00	8.200e+06	1.023e+03	2.000e-05
3.780e+00	8.900e+06	1.023e+03	2.000e-05
6.000e+00	9.600e+06	1.023e+03	2.000e-05
8.360e+00	1.060e+07	1.023e+03	2.000e-05
1.000e+01	1.140e+07	1.023e+03	2.000e-05
1.379e+01	1.310e+07	1.023e+03	2.000e-05
1.665e+01	1.420e+07	1.023e+03	2.000e-05
0.000e+00	4.600e+06	1.123e+03	2.000e-05
1.400e-01	5.700e+06	1.123e+03	2.000e-05
4.300e-01	5.300e+06	1.123e+03	2.000e-05
1.430e+00	5.000e+06	1.123e+03	2.000e-05
3.140e+00	5.000e+06	1.123e+03	2.000e-05
5.210e+00	5.300e+06	1.123e+03	2.000e-05
7.280e+00	5.700e+06	1.123e+03	2.000e-05
1.000e+01	5.600e+06	1.123e+03	2.000e-05
1.286e+01	5.600e+06	1.123e+03	2.000e-05
1.414e+01	6.000e+06	1.123e+03	2.000e-05

Comments on Data

Best compromise for prestraining was found at 2.e-05 s[-1] and 1323 K to create as many mobile dislocations as possible but keep hardening as low as possible.
At 818 K, (lowest temp), silicon can be deformed without cracks.

Reference

ON THE YIELD POINT OF FLOATING-ZONE SILICON SINGLE CRYSTALS. I. YIELD STRESSES AND ACTIVATION PARAMETERS.
Omri, M. Tete, C. Michel, J. P.
George, A.
PHILOS. MAG. A
55 (5), 601-16, 1987.

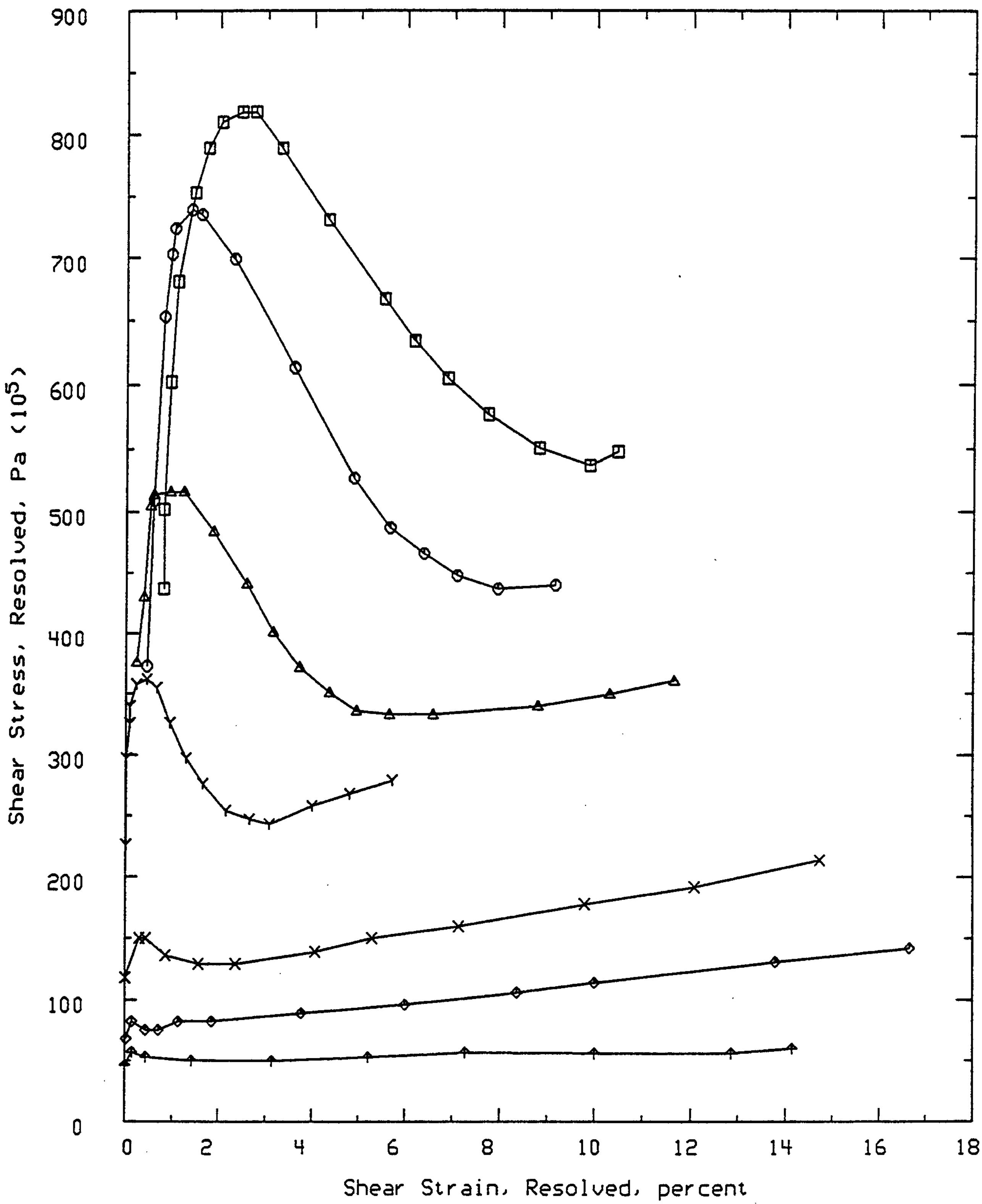

Figure 157 Shear Stress, Resolved of Silicon, n-type

MATERIAL: Silicon: B doped

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 158

****

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :

Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

Specimens were cut with a diamond saw, lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method

Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X	: Boron Dopant Concentration	m^{-3}
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Temperature	K
Z2	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2
0.000e+00	1.040e+07	1.373e+03	2.000e-02
4.000e+25	1.640e+07	1.373e+03	2.000e-02
1.250e+26	1.890e+07	1.373e+03	2.000e-02

Comments on Data

Data was digitized from Figure 4.
Boron-doping causes an increase in lower yielded strength

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

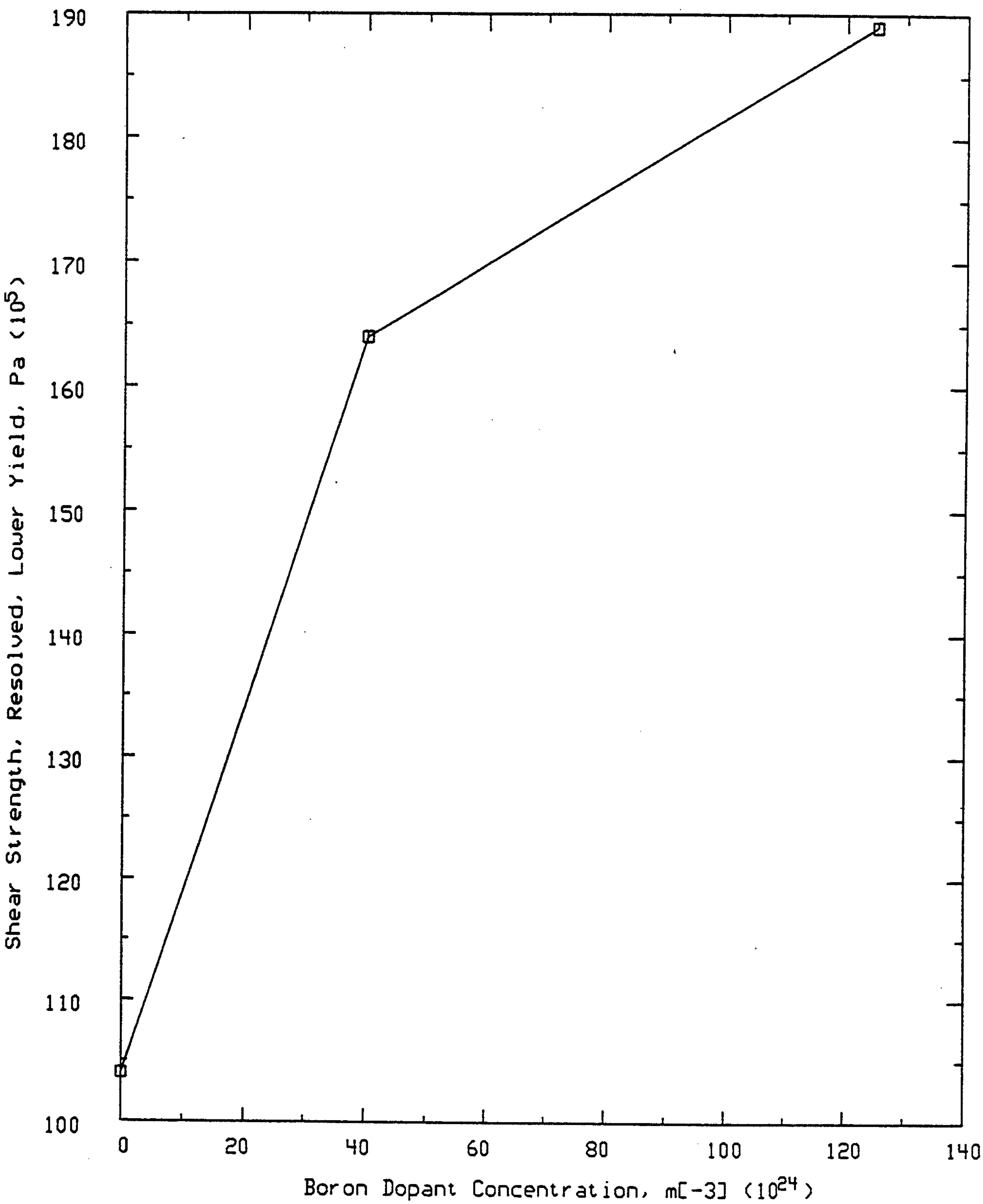

Figure 158 Shear Strength, Resolved, Lower Yield of Silicon: B doped

MATERIAL: Silicon: B doped | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Lower Yield | DATA SET 159
****

Composition

1.25e20 cm^{-3} Boron Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :
Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Specimens were cut with a diamond saw,
lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
4.800e-05	9.200e+06	1.173e+03

1.200e-04	9.900e+06	1.173e+03
2.300e-04	1.160e+07	1.173e+03
4.700e-04	1.580e+07	1.173e+03
1.200e-03	1.990e+07	1.173e+03
2.400e-03	2.420e+07	1.173e+03
1.200e-04	9.900e+06	1.373e+03
2.400e-04	1.030e+07	1.373e+03
4.700e-04	1.030e+07	1.373e+03
1.200e-03	1.030e+07	1.373e+03
2.500e-03	1.110e+07	1.373e+03
4.800e-03	1.290e+07	1.373e+03
1.200e-02	1.770e+07	1.373e+03

Comments on Data

Data was digitized from Figure 1.
Lower yield strength curve at 1173 K intersects the 1373 K curve at a strain rate of 0.1e-03/s. Anomalous behavior is due to solubility of boron in Silicon. As diffusion not being negligible at 1173 K, certain amount of boron precipitates and solute level is decreased. Corresponding decrease of lower yield stress shows that impurities in solute state mainly responsible for observed effects and few precipitated particles do not have much influence on yield point.

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

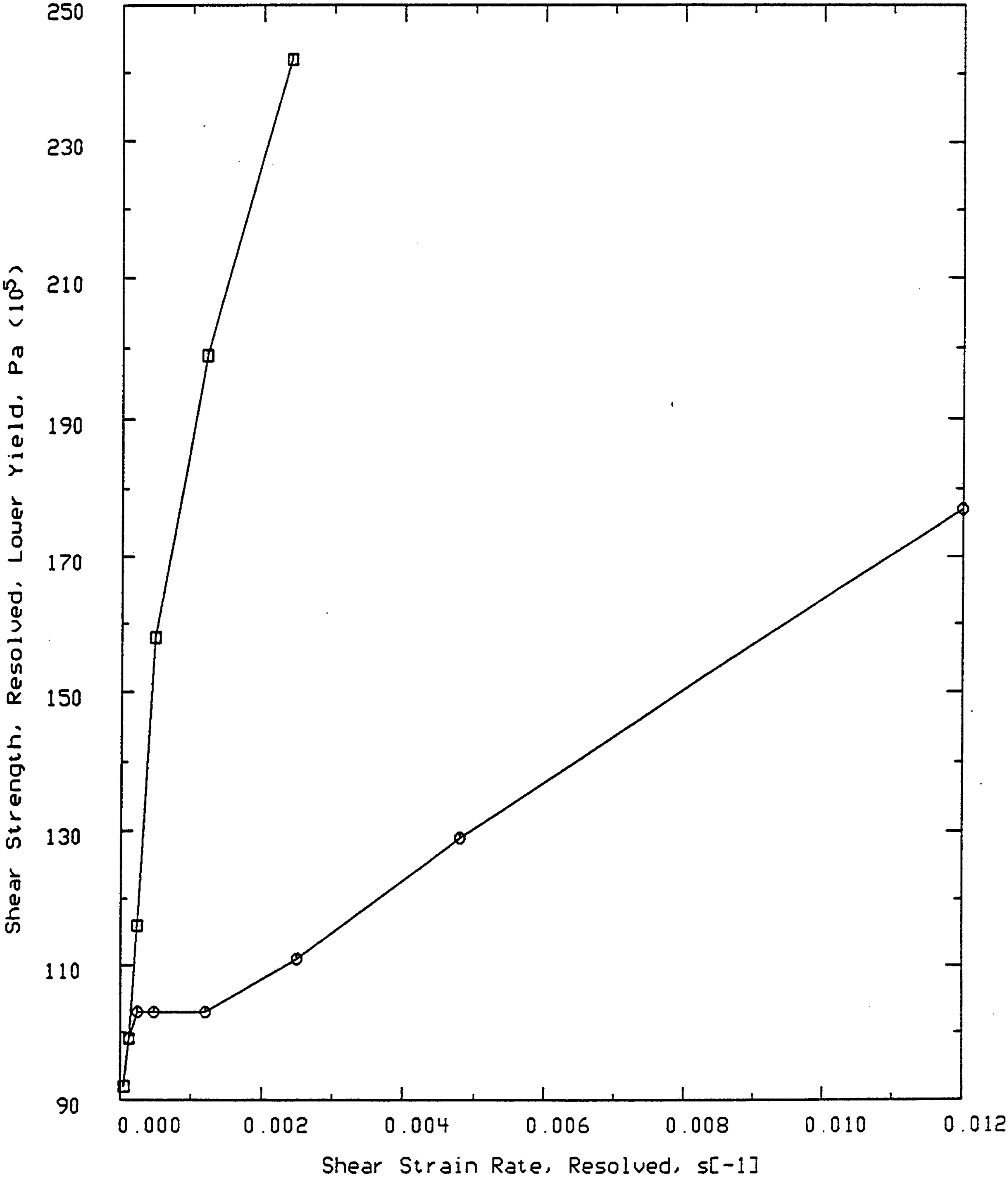

Figure 159 Shear Strength, Resolved, Lower Yield of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 160

****

Composition

4.0e19 cm^{-3} Boron Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :
Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Specimens were cut with a diamond saw,
lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
2.400e-04	1.000e+07	1.173e+03

4.800e-04	1.410e+07	1.173e+03
1.200e-03	1.780e+07	1.173e+03
4.800e-04	7.100e+06	1.273e+03
1.200e-03	1.080e+07	1.273e+03
2.400e-03	1.210e+07	1.273e+03
4.700e-03	1.520e+07	1.273e+03
4.800e-05	3.800e+06	1.373e+03
1.200e-04	4.100e+06	1.373e+03
2.300e-04	4.800e+06	1.373e+03
4.800e-04	4.500e+06	1.373e+03
1.200e-03	6.300e+06	1.373e+03
2.300e-03	8.200e+06	1.373e+03
5.000e-03	1.080e+07	1.373e+03
1.300e-02	1.350e+07	1.373e+03

Comments on Data

Data was digitized from Figure 2.
Lower yielded strength at 1173 K curve intersects the 1373 K curve at strain rate of 0.1e-03/s. Anomalous behavior due to solubility of boron in Silicon. Diffusion not being negligible at 1173 K, certain amount of boron precipitates and solute level decreased. Corresponding decrease of lower yield stress shows that impurities in solute state mainly responsible for observed effects and few precipitated particles do not have much influence on yield strength

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

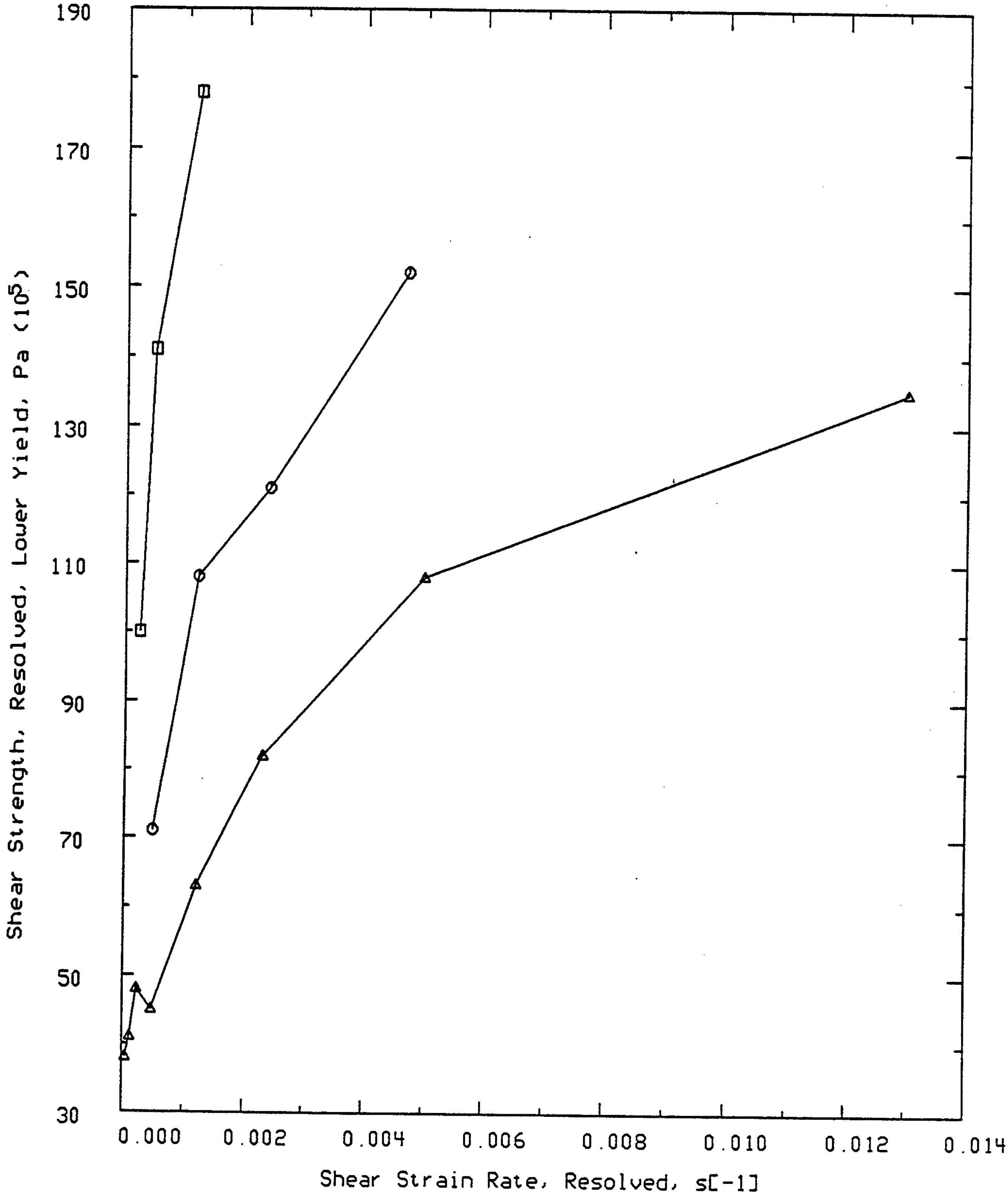

Figure 160 Shear Strength, Resolved, Lower Yield of Silicon: B doped

MATERIAL: Silicon: C doped — HTMIAC/CINDAS 1994, PURDUE UNIVERSITY

PROPERTY: Shear Strength, Resolved, Lower Yield — DATA SET 161

****

Composition

6.0e17 cm^{-3} Oxygen Concentration

Vendor/Producer/Fabricator

Sony Corp. and Komatsu Electronic Metals Co.

Material Preparation

Crystal Growing Method :

Czochralski grown

Descriptors-Textual :

Prior to tensile tests all specimens were subjected to annealing at 1573 K for 2 hours followed by rapid cooling at a rate of 150 C per minute to eliminate possible segregation of carbon and/or oxygen, and also to homogenize the distribution of defects.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Other Properties-Numerical :

Dislocation Density 1.0e06 cm^{-2}

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Tests conducted in vacuum using an Instron machine.

Dislocation density determined by etch-pit technique.

Resolved shear properties derived from recorded data.

Carbon and oxygen concentrations determined by IR absorption.

Parameters-Codified :

Shear Strain Rate, Resolved : 1.1e-04 s[-1]

Pressure : 1.33e-02 pa

Measured/Evaluated Properties

X	: Carbon Concentration	m^{-3}
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Temperature	K

Data Points :

X Y Z1

0.000e+00	1.280e+07	1.073e+03
1.700e+23	1.320e+07	1.073e+03
2.500e+23	1.430e+07	1.073e+03
0.000e+00	7.800e+06	1.173e+03
1.700e+23	8.000e+06	1.173e+03
2.500e+23	9.300e+06	1.173e+03

Comments on Data

Lower yield strength does not seem to depend on carbon content.

Reference

ROLE OF CARBON IN THE STRENGTHENING OF SILICON CRYSTALS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS., PART 2
23 (8), 590-2, 1984.

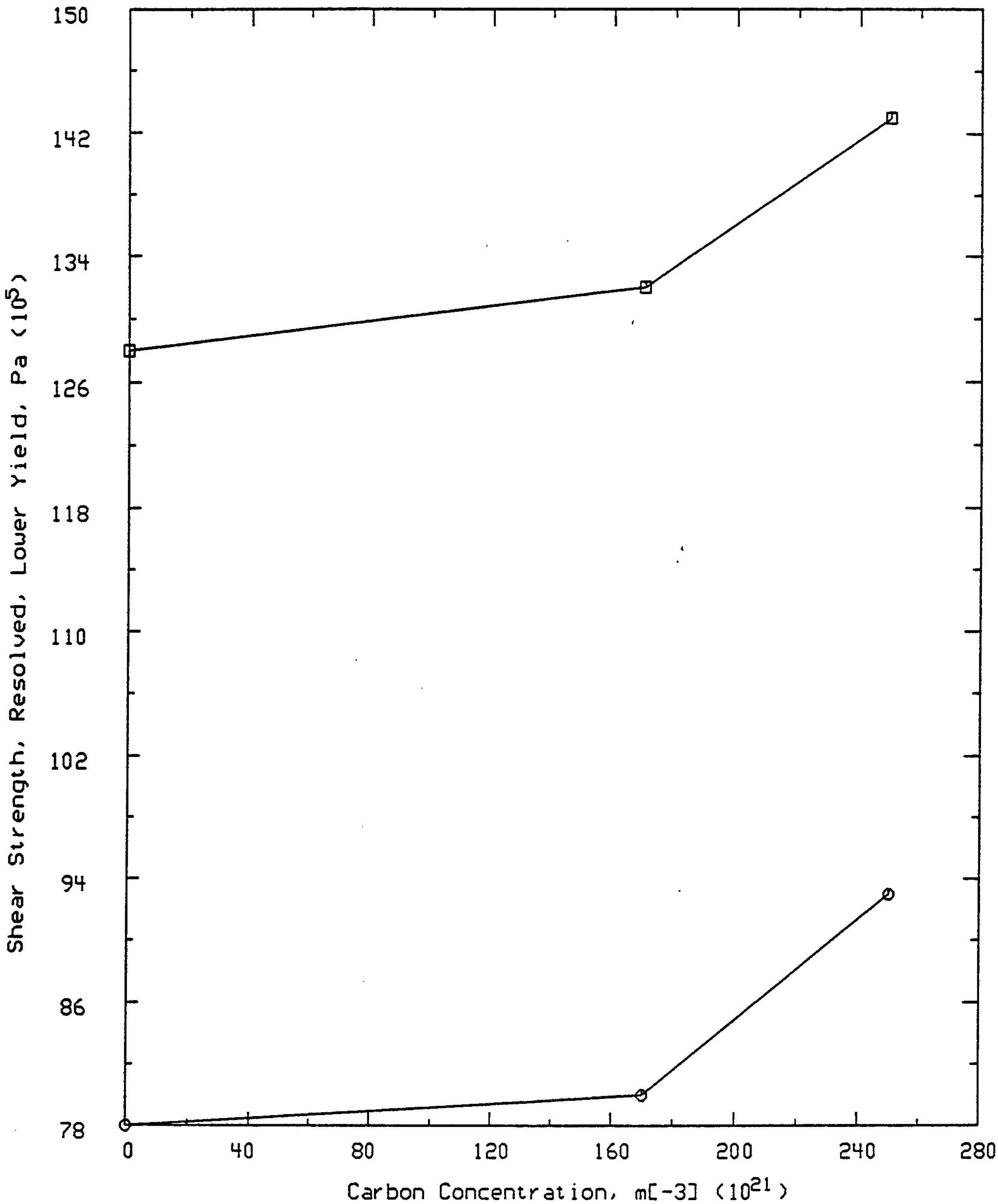

Figure 161 Shear Strength, Resolved, Lower Yield of Silicon: C doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 162

****

Composition

1.0E13	cm^{-3}	Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :

Floating-zone-grown boule, n-type

Additional Preparation/Conditioning

Surface Treatment :

Mechanically polished with one face remaining as-ground.
The specimens were cut using a diamond saw.

Specimen Identification

Dimensions (Geometry) :

Length	9.2	mm
Width	3.8	mm
Thickness	3.8	mm

Orientation With Respect To Material : [100] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	700.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method

Silicon single crystals were deformed in compression at constant strain rates under hydrostatic pressure of 1500 MPa in a solid-confining-medium apparatus.

Parameters-Textual :

The specimen is in contact with a silver jacket. The diffusivity of silver in silicon is so small that during an experiment at the highest temperature (873 K) the penetration of silver is less than one micrometer.

Deformation below 673 K achieved by predeformation at a slower strain rate and temperature above 673 K to eliminate upper yield point. Normal testing then resumed after cooling to desired temperature.

Measured/Evaluated Properties

X : Temperature		K
Y : Shear Strength, Resolved, Lower Yield		Pa
Z1 : Shear Strain Rate, Resolved		s^{-1}

Data Points :

X	Y	Z1
5.870e+02	1.001e+09	5.000e-06
5.870e+02	8.166e+08	5.000e-06
6.870e+02	4.024e+08	5.000e-06
7.350e+02	2.509e+08	5.000e-06
6.870e+02	7.403e+08	5.000e-05
7.390e+02	4.617e+08	5.000e-05
7.820e+02	2.690e+08	5.000e-05
8.820e+02	5.500e+07	5.000e-05

Comments on Data

Data was digitized from Figure 2.
A graph of log yield strength against T suggests a change of slope occurring at 873-923 K. This is taken as the transition temperature. This change of slope could also denote that different thermally activated mechanisms govern the deformation rate at large stresses and low temperatures on one hand and at low stresses and high temperatures on the other.
Measurement uncertainty estimated to be +/- 50 MPa, mostly due to friction.

Reference

THE PLASTIC DEFORMATION OF SILICON BETWEEN 300 DEGREE C AND 600 DEGREE C.
Castaing, J. Veyssiere, P. Kubin, L. P.
Rabier, J.
PHILOS. MAG. A
44 (6), 1407-13, 1981.

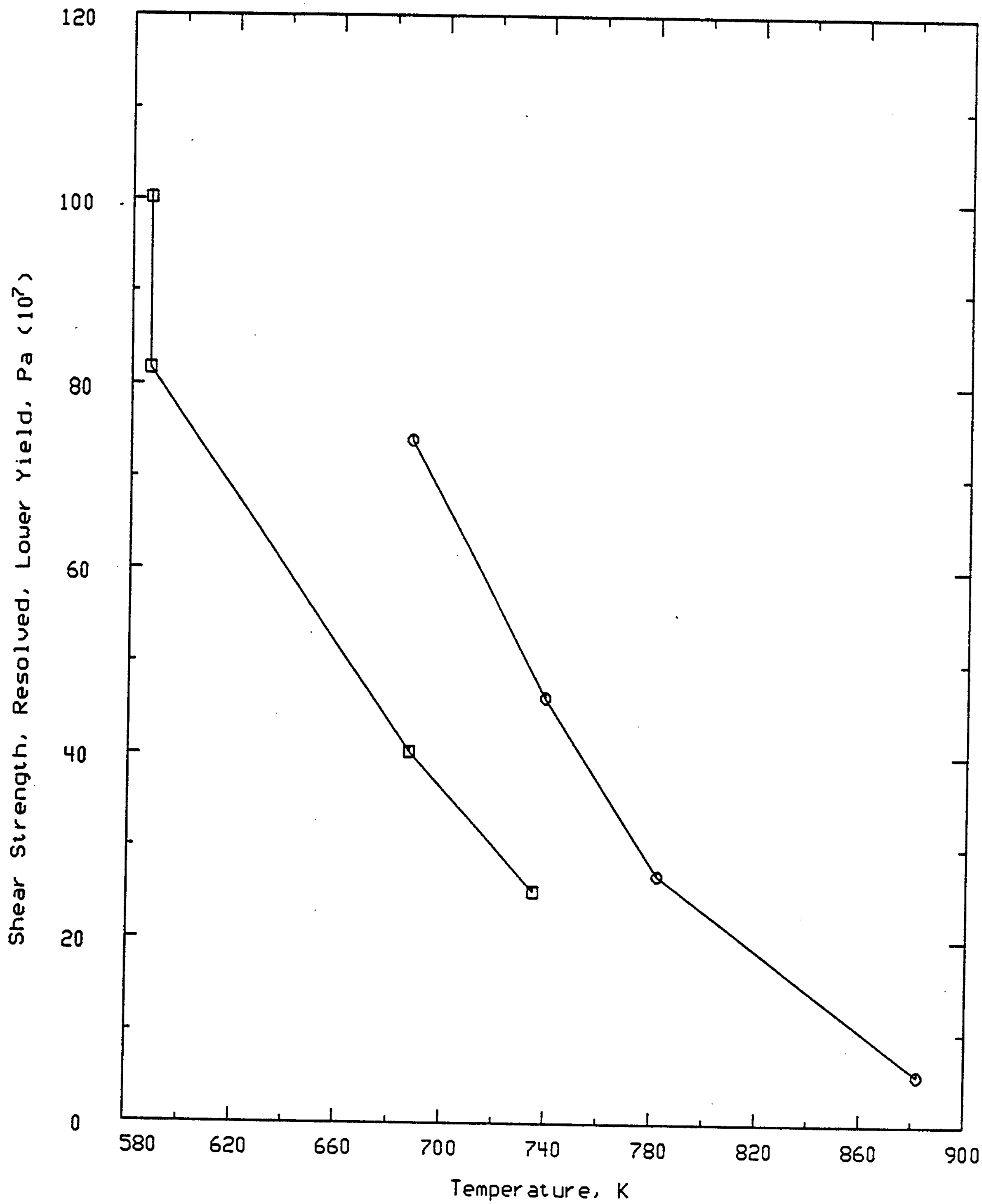

Figure 162 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Lower Yield

****

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :

Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

Specimens were cut with a diamond saw,
lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Parameters-Codified :

Shear Strain Rate, Resolved : 4.8e-03 s[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Phosphorus Dopant Concentration	m^{-3}
Z2	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2
1.372e+03	7.700e+06	5.000e+25	4.800e-03

1.322e+03	1.020e+07	5.000e+25	4.800e-03
1.273e+03	1.250e+07	5.000e+25	4.800e-03
1.224e+03	1.640e+07	5.000e+25	4.800e-03
1.173e+03	2.150e+07	5.000e+25	4.800e-03
1.377e+03	8.100e+06	1.000e+26	4.800e-03
1.270e+03	1.330e+07	1.000e+26	4.800e-03
1.173e+03	2.300e+07	1.000e+26	4.800e-03
1.370e+03	1.080e+07	1.350e+26	2.400e-04
1.271e+03	1.330e+07	1.350e+26	2.400e-04
1.171e+03	1.730e+07	1.350e+26	2.400e-04
1.070e+03	2.290e+07	1.350e+26	2.400e-04
1.372e+03	8.100e+06	1.000e+26	2.400e-04
1.271e+03	1.010e+07	1.000e+26	2.400e-04
1.171e+03	1.350e+07	1.000e+26	2.400e-04
1.070e+03	1.790e+07	1.000e+26	2.400e-04
1.372e+03	6.300e+06	8.000e+25	2.400e-04
1.320e+03	7.700e+06	8.000e+25	2.400e-04
1.271e+03	7.900e+06	8.000e+25	2.400e-04
1.222e+03	9.500e+06	8.000e+25	2.400e-04
1.171e+03	1.070e+07	8.000e+25	2.400e-04

Comments on Data

At high stain rates the activation energy of dislocation velocity measured by lower yield strength was found to be 2 eV for P-doped Silicon. At low strain rates, the lower yield becomes independent of stain rate.

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

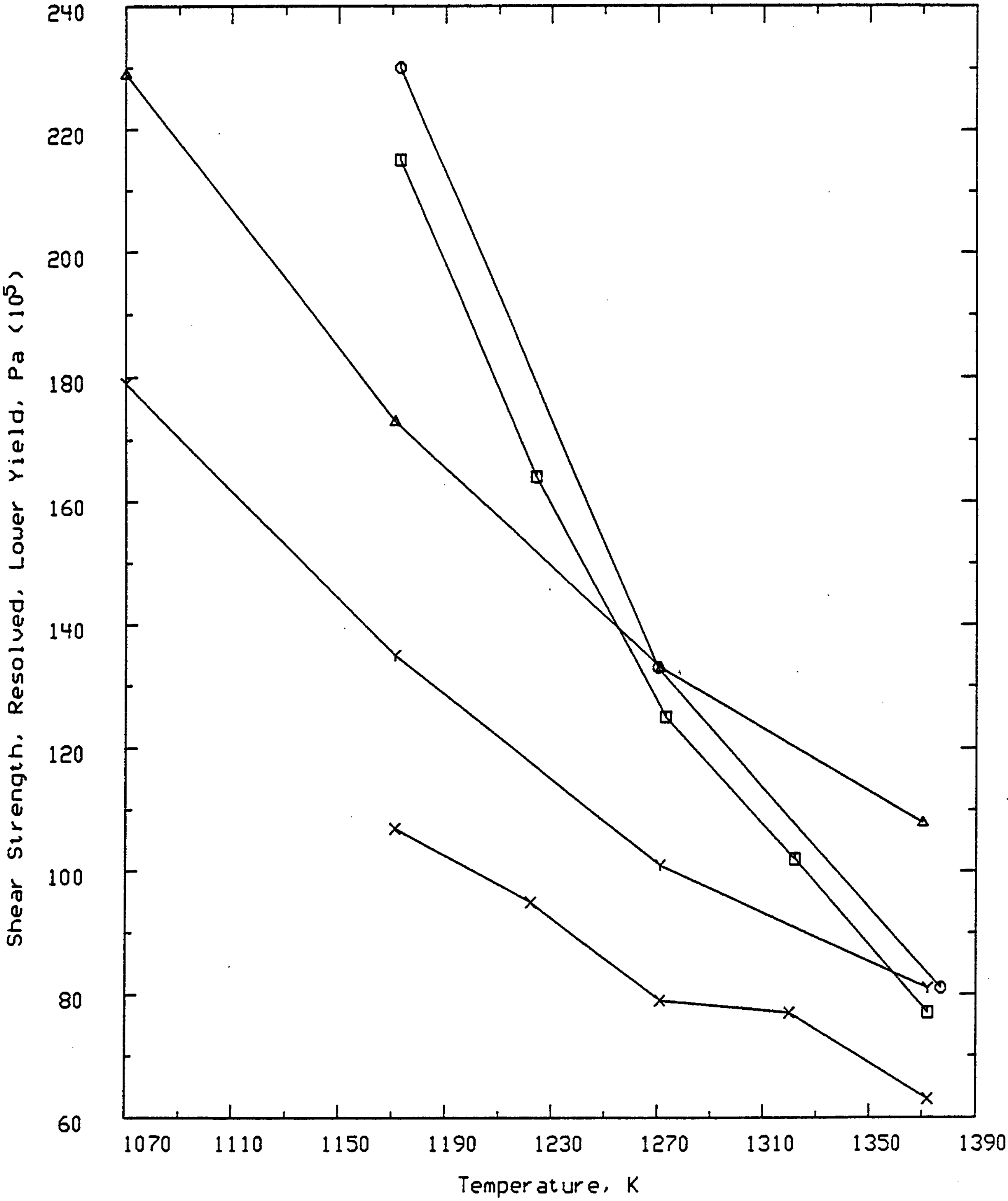

Figure 163 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 164

****

Composition

2.5e14	cm^{-3}	Phosphorus Dopant Concentration
1.0e16	cm^{-3}	Carbon Concentration
1.3e16	cm^{-3}	Oxygen Concentration

Material Preparation

Crystal Growing Method :
Float-zone grown, n-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.	mm
Thickness	3.	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Slip system along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	16.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Testing machine not specified, probably Instron machine.
Resolved shear properties derived from measured stress-strain curves.
Parameters-Codified :
Pressure : 1.e-06 torr

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Lower Yield	Pa
Z1 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Remarks:
1.105e+03	1.063e+07	1.450e-04	smoothed data
1.141e+03	7.940e+06	1.450e-04	
1.174e+03	6.230e+06	1.450e-04	
1.210e+03	4.800e+06	1.450e-04	
1.247e+03	3.710e+06	1.450e-04	
1.288e+03	2.860e+06	1.450e-04	
1.315e+03	2.500e+06	1.450e-04	
1.105e+03	7.700e+06	4.750e-05	smoothed data
1.142e+03	5.600e+06	4.750e-05	
1.175e+03	4.150e+06	4.750e-05	
1.210e+03	3.150e+06	4.750e-05	
1.248e+03	2.470e+06	4.750e-05	
1.290e+03	1.880e+06	4.750e-05	
1.315e+03	1.620e+06	4.750e-05	

Comments on Data

A graph of log yield strength vs. 1/T yield parallel straight lines which is in agreement with the dislocation theory.

Reference

PLASTIC DEFORMATION OF SILICON MONOCRYSTALS OF DIFFERENT BASIC DISLOCATIONS DENSITY IN THE YIELD POINT REGION.
Doerschel, J. Kirscht, F. G.
Baehr, R.
KRIST. TECH.
12 (11), 1191-200, 1977.

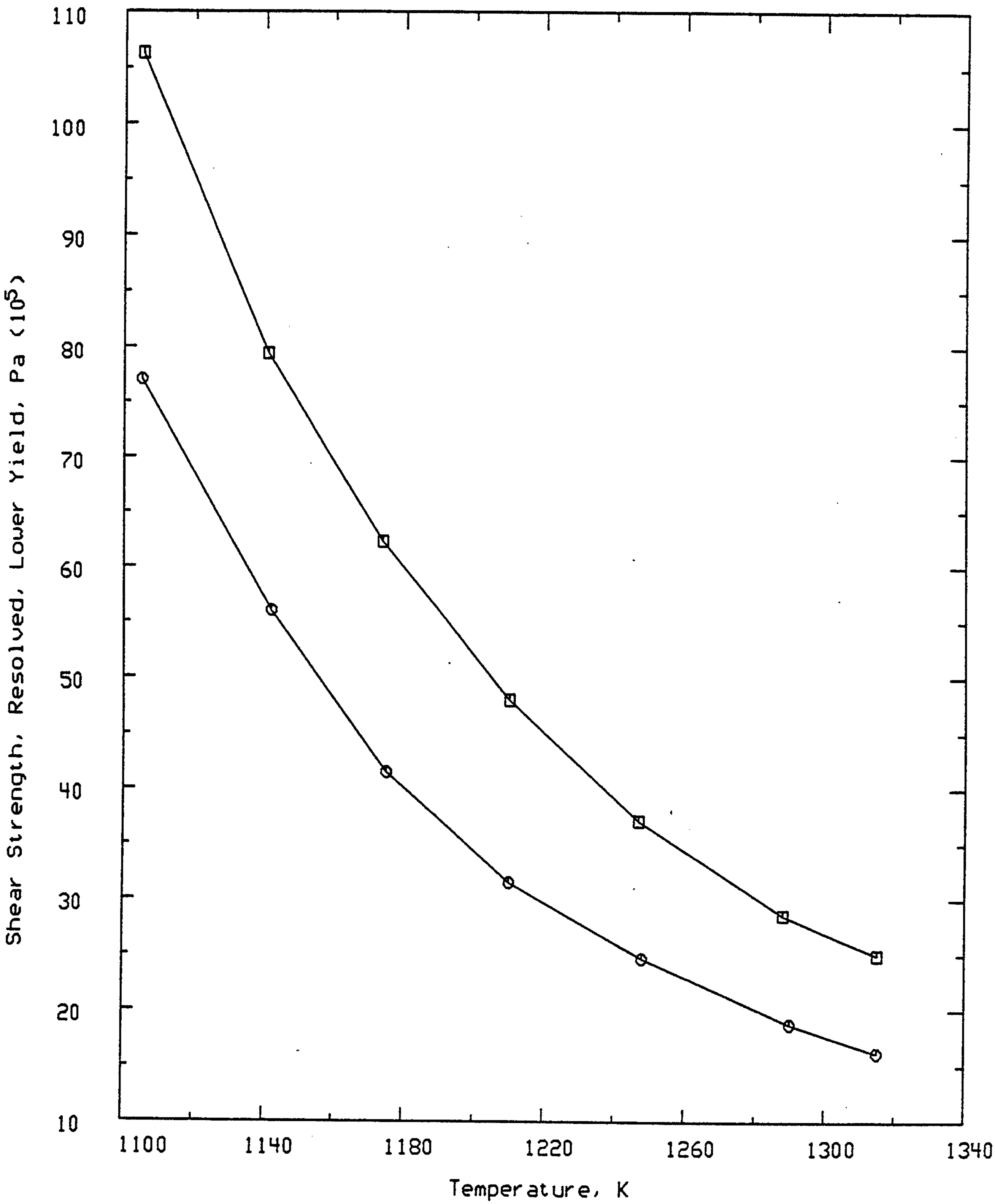

Figure 164 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL:	Silicon: P doped	HTMIAC/CINDAS 1994
		PURDUE UNIVERSITY
PROPERTY:	Shear Strength, Resolved, Lower Yield	DATA SET 165

****

Composition

1.7e13	cm^{-3}	Phosphorus Dopant Concentration
1.0e16	cm^{-3}	Carbon Concentration
8.0e15	cm^{-3}	Oxygen Concentration

Material Preparation

Crystal Growing Method :
Float-zone grown, n-type, grown-in dislocation density

Additional Preparation/Conditioning

Surface Treatment :
Chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.	mm
Thickness	3.	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Slip system along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	250.	Ω cm
Temperature	298.	K

Other Properties-Numerical :

Dislocation Density	6.5e04	cm^{-2}

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Testing machine not specified, probably Instron machine.
Resolved shear properties derived from measured stress-strain curves.
Parameters-Codified :
Pressure : 1.e-06 torr

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Lower Yield	Pa

Z1 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1	Remarks:
1.105e+03	8.480e+06	1.450e-04	smoothed data
1.140e+03	6.430e+06	1.450e-04	
1.174e+03	5.050e+06	1.450e-04	
1.210e+03	3.890e+06	1.450e-04	
1.248e+03	3.100e+06	1.450e-04	
1.288e+03	2.430e+06	1.450e-04	
1.315e+03	2.140e+06	1.450e-04	
1.105e+03	5.560e+06	4.750e-05	smoothed data
1.142e+03	4.220e+06	4.750e-05	
1.175e+03	3.360e+06	4.750e-05	
1.210e+03	2.720e+06	4.750e-05	
1.248e+03	2.170e+06	4.750e-05	
1.288e+03	1.730e+06	4.750e-05	
1.315e+03	1.520e+06	4.750e-05	

Comments on Data

Grown-in dislocation density lowers the yield strength as compared to dislocation-free crystals.
Log yield strength vs. 1/T gave parallel straight lines which is in agreement with the dislocation theory.

Reference

PLASTIC DEFORMATION OF SILICON MONOCRYSTALS OF DIFFERENT BASIC DISLOCATIONS DENSITY IN THE YIELD POINT REGION.
Doerschel, J.   Kirscht, F. G.
Baehr, R.
KRIST. TECH.
12 (11), 1191-200, 1977.

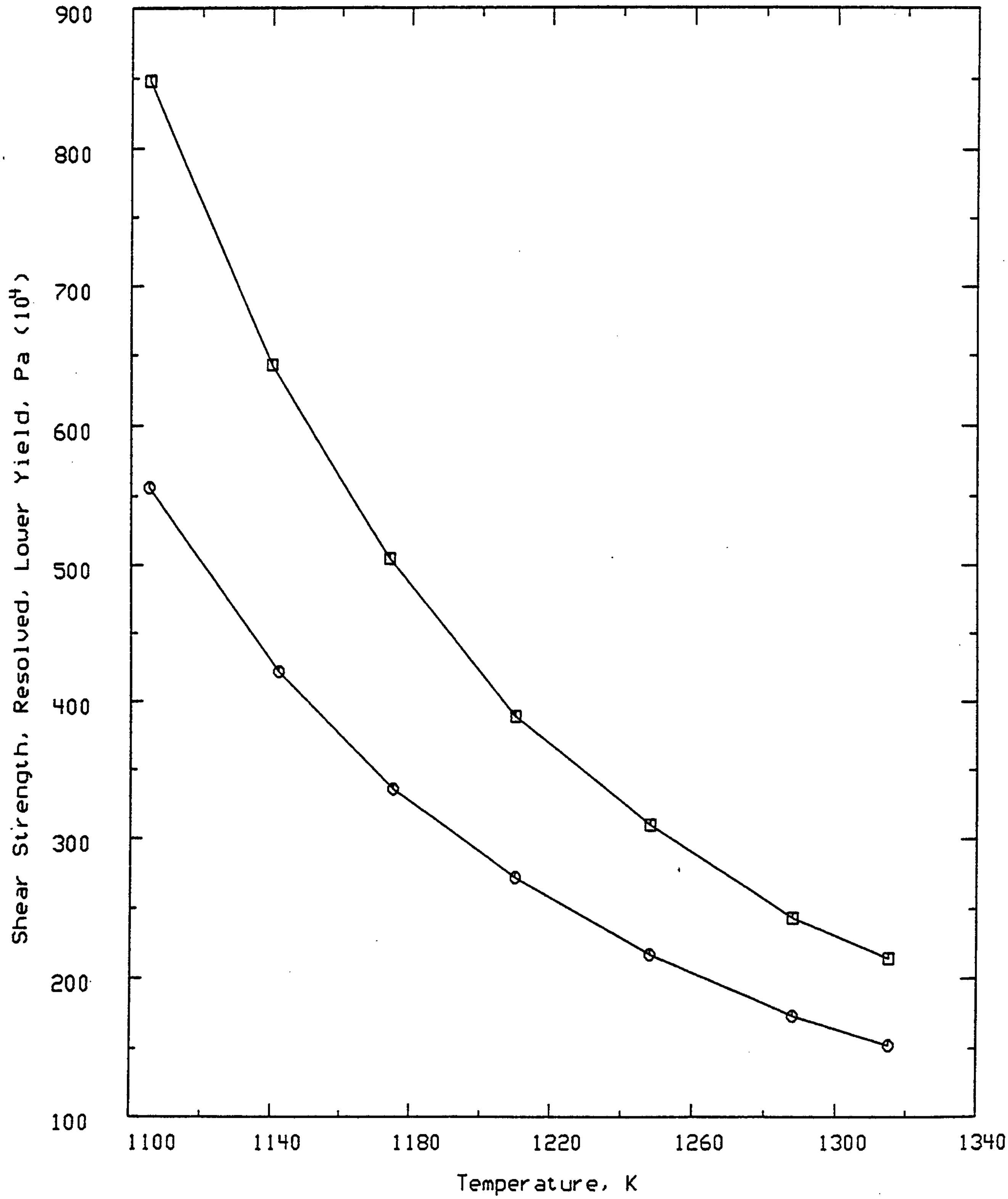

Figure 165 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 166

PROPERTY: Shear Strength, Resolved, Lower Yield

****

Composition

1.0e20 cm^{-3} Phosphorus Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Coating Description :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished
Specimens were cut with a diamond saw.

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Instron machine mounted to a high-temperature apparatus. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2).

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Lower Yield	Pa
Z1 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
1.219e+03	1.760e+07	4.770e-03
1.268e+03	1.330e+07	4.770e-03
1.321e+03	1.100e+07	4.770e-03
1.370e+03	9.300e+06	4.770e-03
1.170e+03	1.700e+07	2.390e-03
1.268e+03	1.170e+07	2.390e-03

1.370e+03	8.100e+06	2.390e-03
1.370e+03	7.600e+06	2.390e-04
1.316e+03	8.800e+06	2.390e-04
1.268e+03	9.500e+06	2.390e-04
1.268e+03	1.020e+07	2.390e-04
1.221e+03	1.060e+07	2.390e-04
1.172e+03	1.360e+07	2.390e-04
1.168e+03	1.280e+07	2.390e-04
1.119e+03	1.490e+07	2.390e-04
1.071e+03	1.770e+07	2.390e-04
1.071e+03	1.840e+07	2.390e-04

Comments on Data

A graph of log yield strength vs. 1/T yields straight lines of slopes different than the ones obtained for pure silicon.

Reference

THE INITIAL STAGE OF PLASTIC DEFORMATION OF SILICON HIGHLY DOPED WITH PHOSPHORUS.
Siethoff, H.
ACTA METALL.
17, 793-801, 1969.

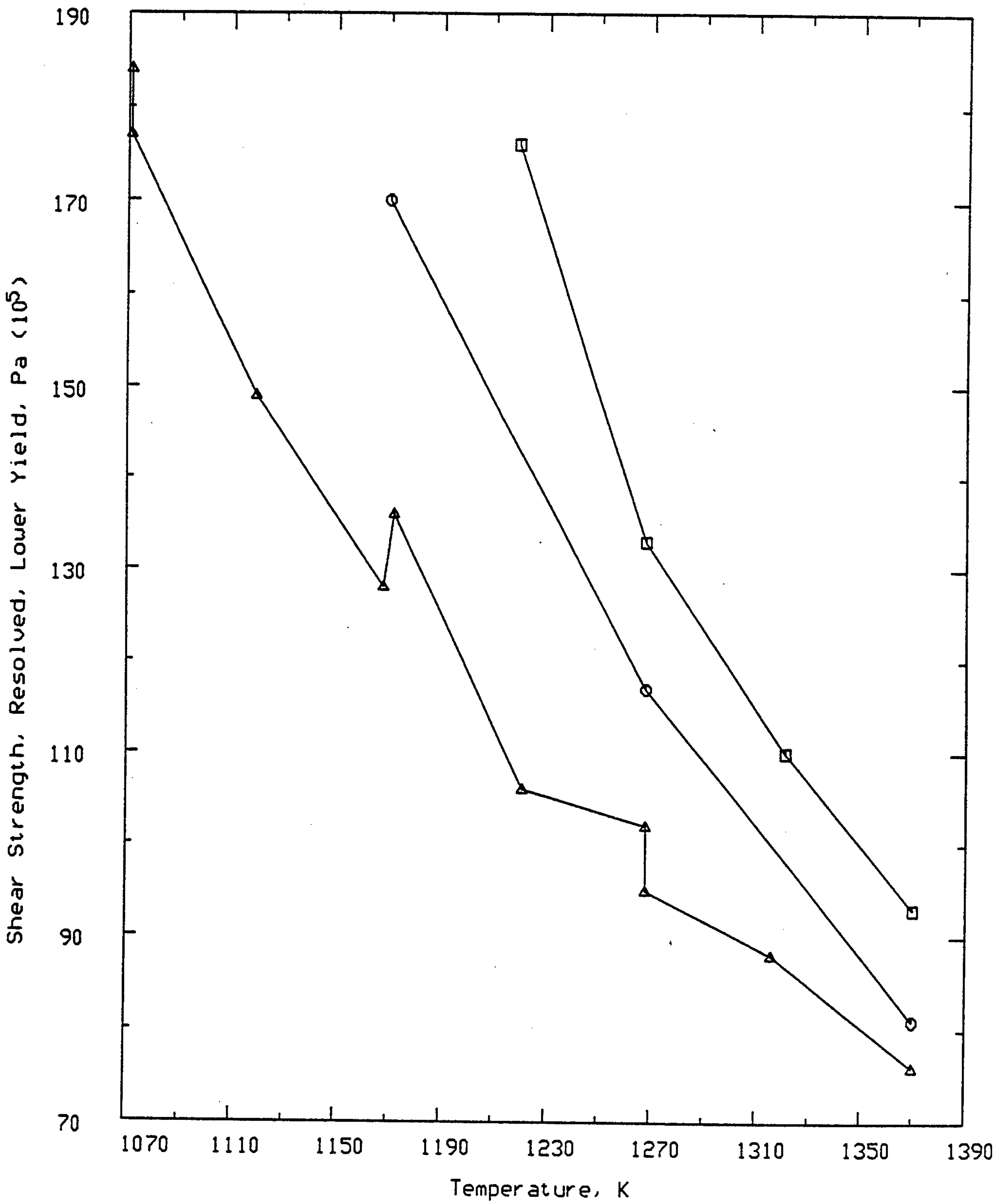

Figure 166 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 167

****

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :

Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

Specimens were cut with a diamond saw,
lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X : Phosphorus Dopant Concentration	m^{-3}
Y : Shear Strength, Resolved, Lower Yield	Pa
Z1 : Temperature	K
Z2 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2
0.000e+00	1.040e+07	1.373e+03	2.000e-02
5.100e+25	1.240e+07	1.373e+03	2.000e-02
1.000e+26	1.350e+07	1.373e+03	2.000e-02

1.300e+26	1.400e+07	1.373e+03	2.000e-02

Comments on Data

Phosphorus-doping shows a weak increase in lower yield strength as compared to boron-doping

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

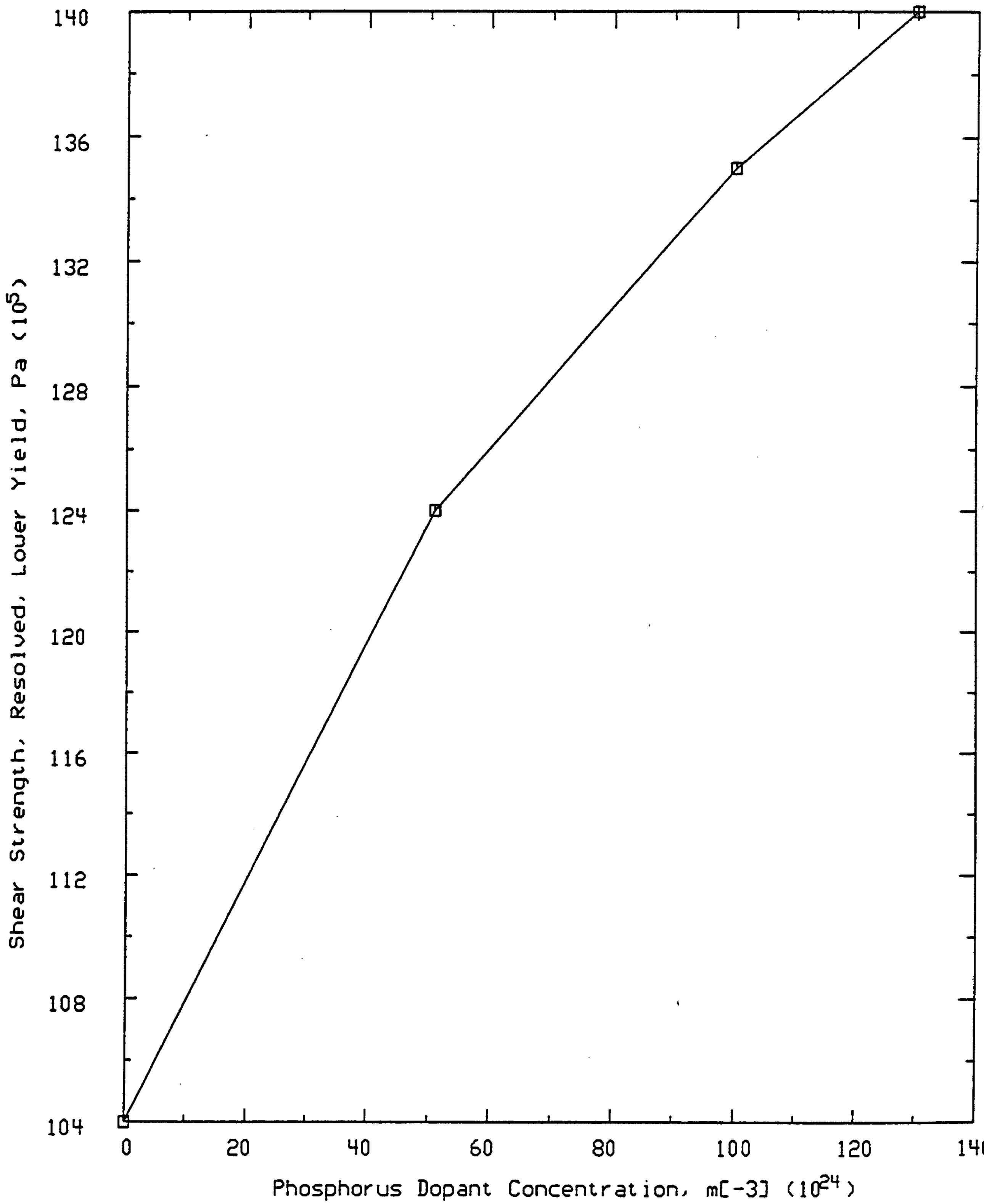

Figure 167 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 168

PROPERTY: Shear Strength, Resolved, Lower Yield

****

Composition

1.0e20	cm^{-3}	Phosphorus Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Coating Description :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished
Specimens were cut with a diamond saw.

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Instron machine mounted to a high-temperature apparatus. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2).

Measured/Evaluated Properties

X : Shear Strain Rate, Resolved	s^{-1}
Y : Shear Strength, Resolved, Lower Yield	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
2.500e-04	1.350e+07	1.173e+03
4.800e-04	1.310e+07	1.173e+03
1.200e-03	1.350e+07	1.173e+03
2.500e-03	1.720e+07	1.173e+03
1.300e-04	9.700e+06	1.273e+03
2.400e-04	1.030e+07	1.273e+03

4.800e-04	1.000e+07	1.273e+03
1.200e-03	1.030e+07	1.273e+03
2.500e-03	1.160e+07	1.273e+03
4.900e-03	1.350e+07	1.273e+03
1.200e-02	1.780e+07	1.273e+03
2.500e-04	7.800e+06	1.373e+03
4.800e-04	8.000e+06	1.373e+03
2.500e-03	8.300e+06	1.373e+03
4.800e-03	9.100e+06	1.373e+03
1.200e-02	1.160e+07	1.373e+03
2.400e-02	1.440e+07	1.373e+03

Comments on Data

Lower yield strength of the heavily doped crystals showed marked deviations from that of pure and low doped crystals especially at low stain rates. Behavior interpreted as solid solution hardening due to electrostatic interaction between dislocations and solute atoms.

Reference

THE INITIAL STAGE OF PLASTIC DEFORMATION OF SILICON HIGHLY DOPED WITH PHOSPHORUS.
Siethoff, H.
ACTA METALL.
17, 793-801, 1969.

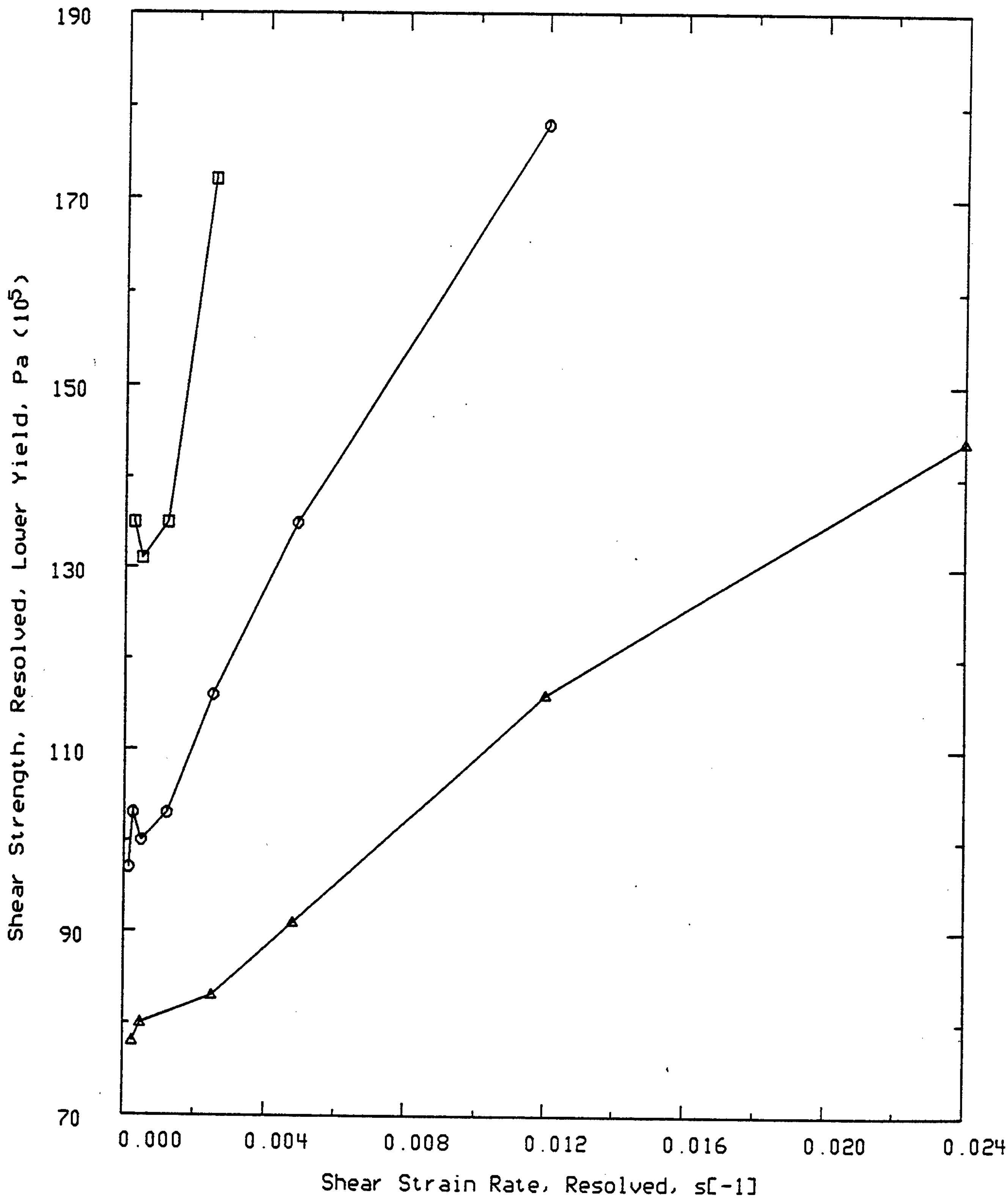

Figure 168 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon: P doped — HTMIAC/CINDAS 1994, PURDUE UNIVERSITY

PROPERTY: Shear Strength, Resolved, Lower Yield — DATA SET 169

****

Composition

1.e18	cm^{-3}	Oxygen Concentration
2.e16	cm^{-3}	Carbon Concentration

Vendor/Producer/Fabricator

KOFU Works of Hitachi Ltd.

Material Preparation

Crystal Growing Method :

Czochralski grown, dislocation free, n-type
Grown with diameter of 76 mm in the [111] direction.

Descriptors-Textual :

Annealed at 1323. K for various times.

Additional Preparation/Conditioning

Surface Treatment :

Surface layers polished and removed to depth more than 250 microns.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	7-9	Ω cm
Temperature	298	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading
Test conducted in vacuum using Instrom machine mounted to high temperature apparatus. Resolved shear properties derived from measured data.

Parameters-Codified :

Pressure : 1.e-05 Torr
Shear Strain, Resolved : 1.1e-04 s[-1]
Temperature : 1173. K
Annealing Temperature : 1323. K

Measured/Evaluated Properties

X : Annealing Time — s

Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Annealing Temperature	K
Z2	: Temperature	K
Z3	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2	Z3
0.000e+00	1.360e+07	1.323e+03	1.173e+03	1.100e-04
1.019e+04	1.230e+07	1.323e+03	1.173e+03	1.100e-04
1.022e+04	1.170e+07	1.323e+03	1.173e+03	1.100e-04
2.063e+04	7.600e+06	1.323e+03	1.173e+03	1.100e-04
4.165e+04	6.400e+06	1.323e+03	1.173e+03	1.100e-04
8.471e+04	6.400e+06	1.323e+03	1.173e+03	1.100e-04
1.719e+05	6.800e+06	1.323e+03	1.173e+03	1.100e-04

Comments on Data

Yield strength decreased drastically with annealing time in the range of 0 to 10 hours; longer annealing time did not significantly reduce yield strength.

Reference

MECHANICAL BEHAVIOR OF CZOCHRALSKI-SILICON CRYSTALS AS AFFECTED BY PRECIPITATION AND DISSOLUTION OF OXYGEN ATOMS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS.
21 (1), 47-55, 1982.

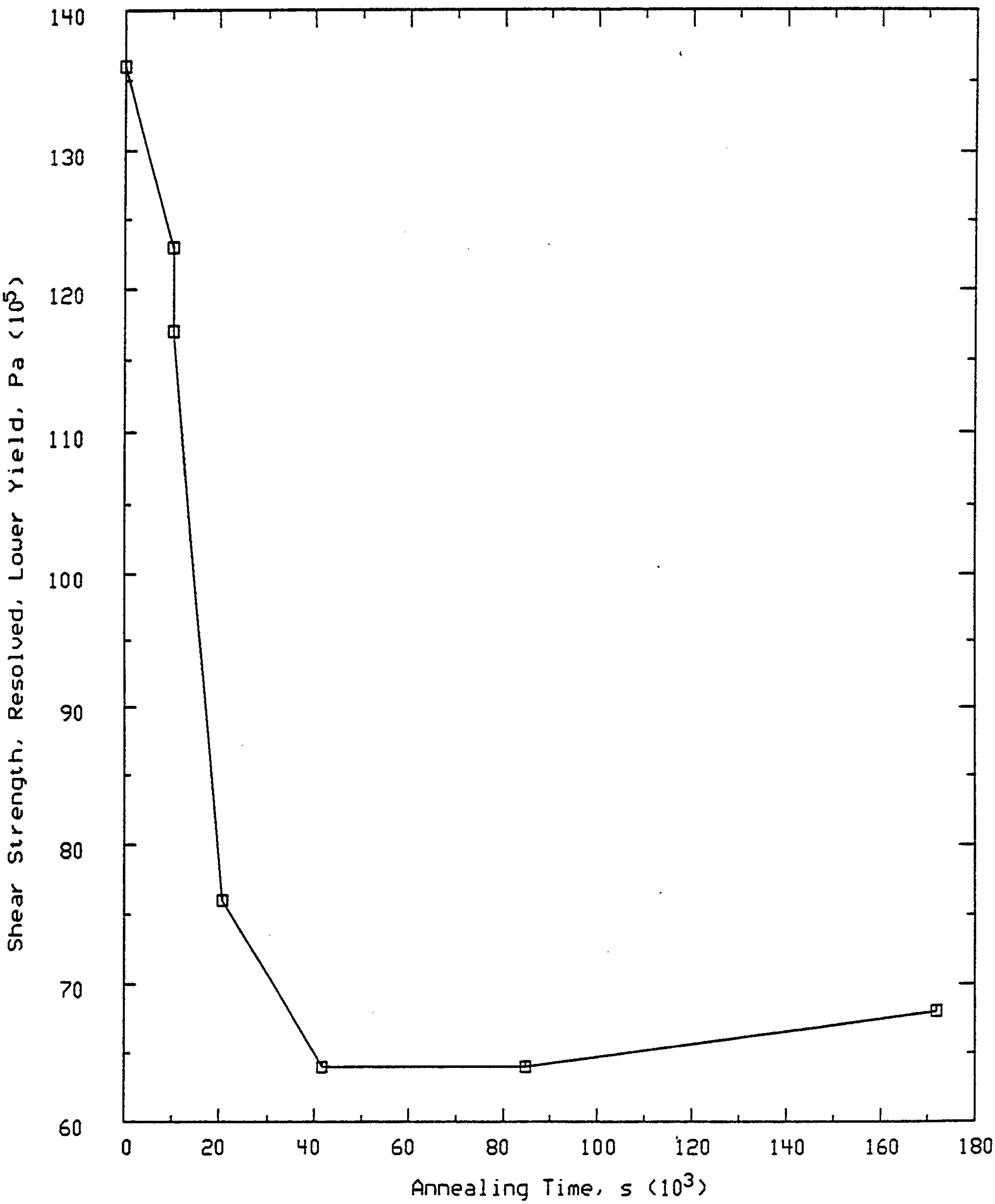

Figure 169 Shear Strength, Resolved, Lower Yield of Silicon: P doped

MATERIAL: Silicon, n-type

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 170

****

Vendor/Producer/Fabricator

Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation

Crystal Growing Method :

Float-zone technique

Crystal grown in a high purity argon gas atmosphere.

Descriptors-Textual :

Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :		
Electrical Resistivity	460.	Ω cm
Temperature	298.	K
Other Properties-Numerical :		
Dislocation Density	2.0e04	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Parameters-Textual :

Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.

Parameters-Codified :

Pressure : 1.3e-02 Pa

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X : Temperature		K
Y : Shear Strength, Resolved, Lower Yield		Pa

Z1 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1
1.076e+03	2.220e+07	6.000e-04
1.170e+03	1.160e+07	6.000e-04
1.272e+03	5.600e+06	6.000e-04
1.073e+03	1.380e+07	1.200e-04
1.073e+03	1.270e+07	1.200e-04
1.122e+03	9.000e+06	1.200e-04
1.173e+03	5.600e+06	1.200e-04
1.222e+03	4.000e+06	1.200e-04
1.268e+03	3.200e+06	1.200e-04

Comments on Data

A graph of log yield strength vs. 1/T gave straight lines with an activation energy of 0.8 eV.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A
50, 685-93, 1978.

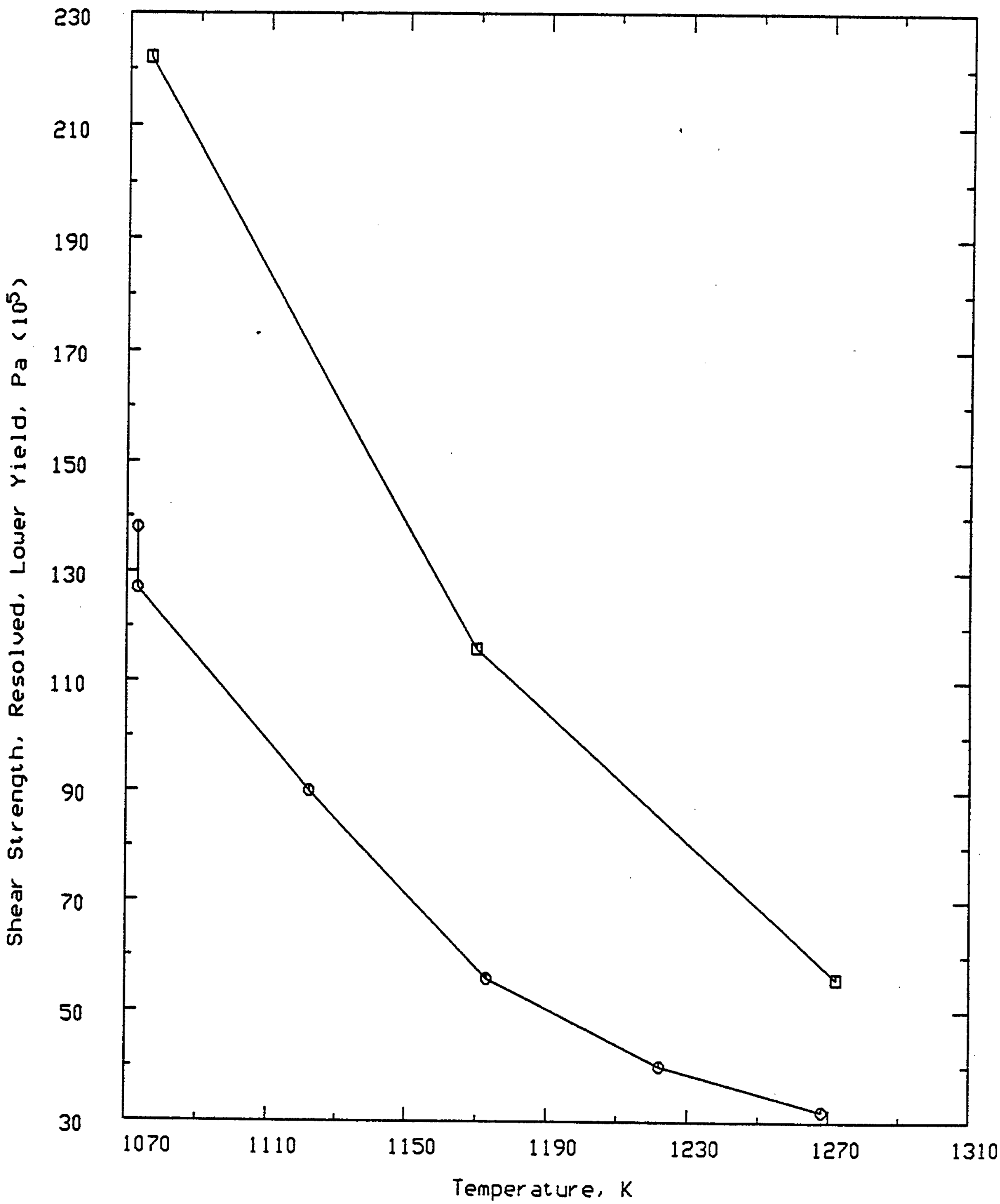

Figure 170 Shear Strength, Resolved, Lower Yield of Silicon, n-type

MATERIAL:	Silicon, n-type	HTMIAC/CINDAS 1994
		PURDUE UNIVERSITY
PROPERTY:	Shear Strength, Resolved, Lower Yield	DATA SET 171

****

Vendor/Producer/Fabricator

Wacker

Material Preparation

Crystal Growing Method :

Float-zone grown, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

{111} and {541} side faces cut with a diamond saw and diamond polished (1/4 micron)

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Thickness	4.25	mm
Width	4.25	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Specimen oriented to obtain a single slip deformation along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	>5.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

High-temperature compression stage apparatus mounted on an Instron machine. A continuous flow of forming gas (10 pct. H(2), 90 pct. N(2)) maintained during each test. Curves of resolved shear stress - strain derived from the recorded data.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
9.770e+02	1.470e+07	2.000e-05
1.000e+03	1.350e+07	2.000e-05
1.026e+03	9.600e+06	2.000e-05
1.078e+03	5.800e+06	2.000e-05
1.128e+03	3.600e+06	2.000e-05
1.177e+03	2.600e+06	2.000e-05
1.227e+03	2.800e+06	2.000e-05
1.279e+03	2.800e+06	2.000e-05
1.329e+03	2.400e+06	2.000e-05
1.378e+03	2.000e+06	2.000e-05
1.430e+03	1.200e+06	2.000e-05
1.477e+03	7.500e+05	2.000e-05
1.527e+03	5.500e+05	2.000e-05
1.577e+03	5.400e+05	2.000e-05
1.128e+03	1.020e+07	2.000e-04
1.180e+03	6.200e+06	2.000e-04
1.230e+03	5.400e+06	2.000e-04
1.279e+03	4.000e+06	2.000e-04
1.334e+03	3.600e+06	2.000e-04
1.378e+03	3.000e+06	2.000e-04
1.428e+03	2.000e+06	2.000e-04
1.477e+03	1.400e+06	2.000e-04
1.527e+03	1.100e+06	2.000e-04

Comments on Data

At the lower strain rate, the temperature dependence consists of three stages. The low-temperature range in which the yield strength decreases rapidly with increasing temperature followed from about 1170 - 1320 K by a plateau where it remains constant or even slightly increases with temperature. At higher temperatures the flow stress extrapolated from stage I of easy glide decreases again. At higher strain rate the plateau no longer appears.

Reference

ON THE YIELD POINT OF FLOATING-ZONE SILICON SINGLE CRYSTALS. I. YIELD STRESSES AND ACTIVATION PARAMETERS.
Omri, M. Tete, C. Michel, J. P.
George, A.
PHILOS. MAG. A
55 (5), 601-16, 1987.

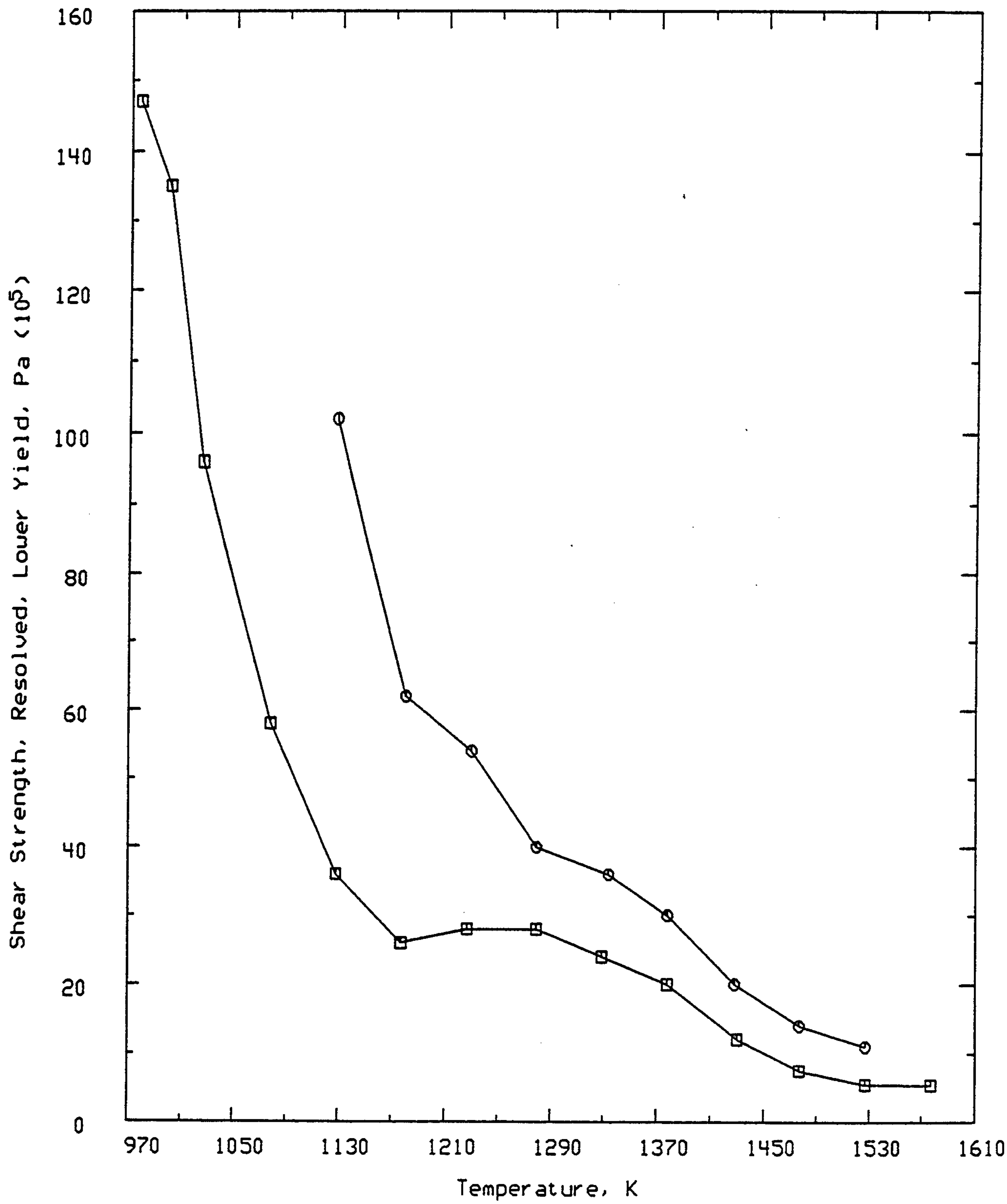

Figure 171 Shear Strength, Resolved, Lower Yield of Silicon, n-type

MATERIAL: Silicon, n-type | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY

PROPERTY: Shear Strength, Resolved, Lower Yield | DATA SET 172

****

Vendor/Producer/Fabricator

Wacker

Material Preparation

Crystal Growing Method :

Float-zone grown, dislocation-free

Descriptors-Textual :

crystal pre-strained to extend temperature range towards lower range

Additional Preparation/Conditioning

Surface Treatment :

{111} and {541} side faces cut with a diamond saw and diamond polished (1/4 micron)

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Thickness	4.25	mm
Width	4.25	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Specimen oriented to obtain a single slip deformation along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	>5.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

High-temperature compression stage apparatus mounted on an Instron machine. A continuous flow of forming gas (10 pct. H(2), 90 pct. N(2)) maintained during each test. Curves of resolved shear stress - strain derived from the recorded data.

Parameters-Codified :

Pre-Strain Rate, Plastic : 7.e-02 pct. (shear)

Shear Strain Rate, Resolved : 2.e-05 s[-1] (pre-straining)

Pre-Strain Temperature : 1323. K

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
8.150e+02	5.390e+07	2.000e-05
8.270e+02	4.310e+07	2.000e-05
8.340e+02	3.340e+07	2.000e-05
8.470e+02	3.260e+07	2.000e-05
8.750e+02	2.220e+07	2.000e-05
8.980e+02	1.830e+07	2.000e-05
9.220e+02	1.340e+07	2.000e-05
9.480e+02	1.160e+07	2.000e-05
9.740e+02	9.800e+06	2.000e-05
1.000e+03	8.800e+06	2.000e-05
1.023e+03	7.700e+06	2.000e-05
1.047e+03	7.300e+06	2.000e-05
1.075e+03	7.300e+06	2.000e-05
1.120e+03	6.900e+06	2.000e-05
8.720e+02	3.640e+07	8.000e-05
9.000e+02	2.560e+07	8.000e-05
9.240e+02	2.040e+07	8.000e-05
9.720e+02	1.440e+07	8.000e-05
1.023e+03	1.010e+07	8.000e-05
1.073e+03	8.700e+06	8.000e-05
8.720e+02	5.210e+07	2.000e-04
8.950e+02	3.810e+07	2.000e-04
9.230e+02	2.800e+07	2.000e-04
9.700e+02	1.790e+07	2.000e-04
1.023e+03	1.290e+07	2.000e-04
1.070e+03	1.010e+07	2.000e-04
1.123e+03	8.900e+06	2.000e-04

Comments on Data

Lower yield strength of pre-strained crystals did not exhibit the same plateau observed for the as-received crystals at all temperatures.
Pre-straining conditions (2.e-05 s[-1] at 1323 K) chosen to create as many mobile dislocations as possible but at the same time keep hardening as low as possible.

Reference

ON THE YIELD POINT OF FLOATING-ZONE SILICON SINGLE CRYSTALS. I. YIELD STRESSES AND ACTIVATION PARAMETERS.
Omri, M. Tete, C. Michel, J. P.
George, A.
PHILOS. MAG. A
55 (5), 601-16, 1987.

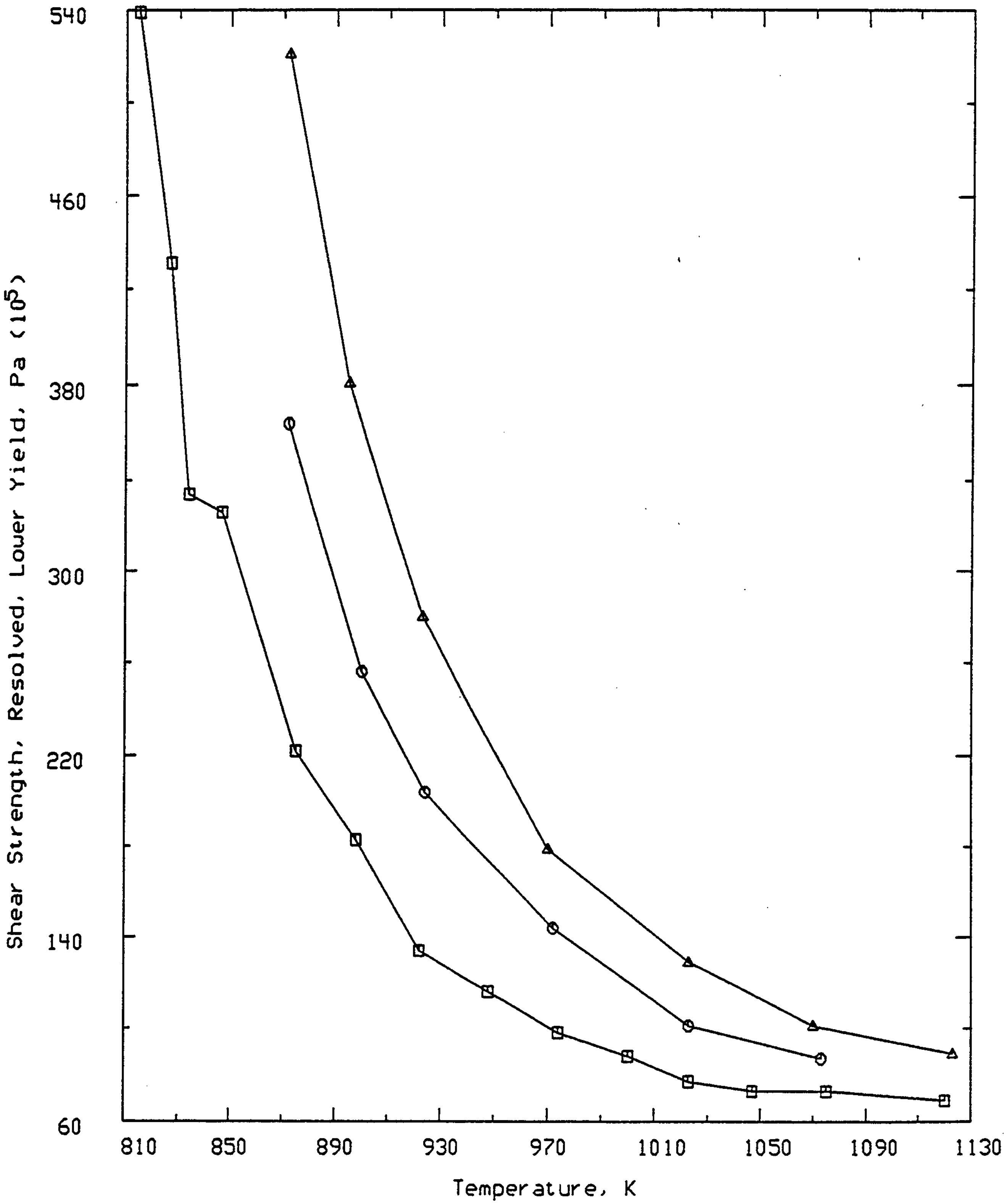

Figure 172 Shear Strength, Resolved, Lower Yield of Silicon, n-type

MATERIAL: Silicon, n-type

PROPERTY: Shear Strength, Resolved, Lower Yield

****

Vendor/Producer/Fabricator

Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation

Crystal Growing Method :

Float-zone technique

Crystal grown in a high purity argon gas atmosphere.

Descriptors-Textual :

Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	460.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Parameters-Textual :

Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.

Parameters-Codified :

Pressure : 1.3e-02 Pa

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X : Dislocation Density	m^{-2}
Y : Shear Strength, Resolved, Lower Yield	Pa
Z1 : Temperature	K
Z2 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2
1.600e+08	2.200e+07	1.073e+03	6.000e-04
1.400e+09	2.190e+07	1.073e+03	6.000e-04
3.900e+09	1.870e+07	1.073e+03	6.000e-04
8.900e+09	1.490e+07	1.073e+03	6.000e-04
1.800e+10	1.440e+07	1.073e+03	6.000e-04
4.300e+10	1.490e+07	1.073e+03	6.000e-04
1.600e+08	1.230e+07	1.073e+03	1.200e-04
5.900e+08	1.230e+07	1.073e+03	1.200e-04
1.900e+09	1.230e+07	1.073e+03	1.200e-04
2.400e+09	1.120e+07	1.073e+03	1.200e-04
8.900e+09	9.000e+06	1.073e+03	1.200e-04
1.000e+10	1.060e+07	1.073e+03	1.200e-04
1.700e+10	9.000e+06	1.073e+03	1.200e-04
4.500e+10	7.900e+06	1.073e+03	1.200e-04
1.600e+08	5.400e+06	1.173e+03	1.200e-04
1.800e+09	4.200e+06	1.173e+03	1.200e-04
3.700e+09	4.200e+06	1.173e+03	1.200e-04
1.300e+10	3.700e+06	1.173e+03	1.200e-04

Comments on Data

Dislocation density determined by etch-pit technique.
Lower yield strength, unlike upper yield, does not seem to be affected by dislocation density.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A
50, 685-93, 1978.

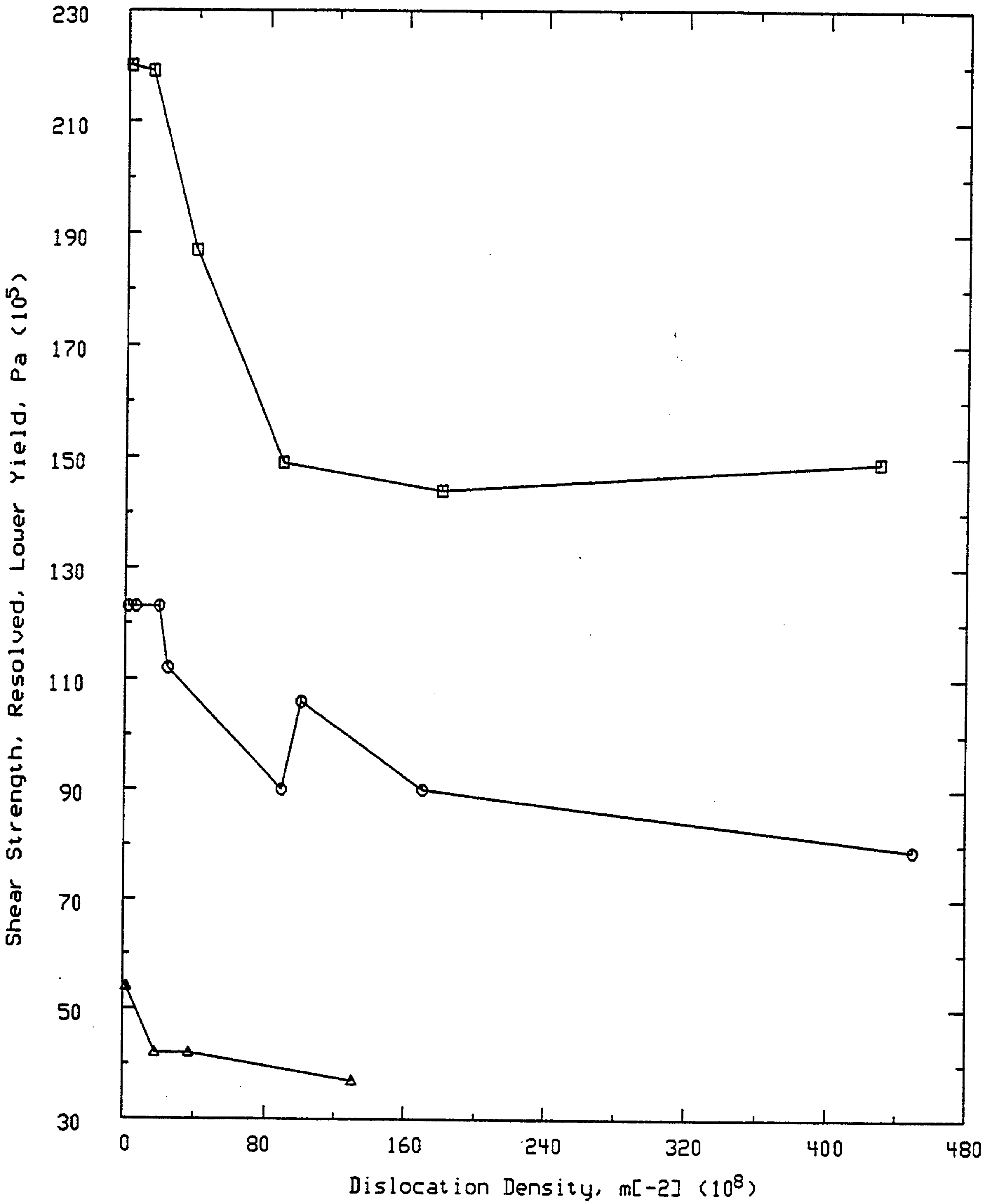

Figure 173 Shear Strength, Resolved, Lower Yield of Silicon, n-type

MATERIAL: Silicon, n-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Lower Yield	DATA SET 174

****

Vendor/Producer/Fabricator
Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation
Crystal Growing Method :
Float-zone technique
Crystal grown in a high purity argon gas atmosphere.
Descriptors-Textual :
Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification
Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :		
Electrical Resistivity	460.	Ω cm
Temperature	298.	K
Other Properties-Numerical :		
Dislocation Density	2.0e04	cm^{-2}

Measurement/Evaluation Method
Name/Description :
Shear Response Under Tensile Loading
Parameters-Textual :
Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.
Parameters-Codified :
Pressure : 1.3e-02 Pa

Experimental Conditioning/Material Degradation
Conditioning/Degradation/Environment : Vacuum Environment
Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X : Shear Strain Rate, Resolved	s^{-1}
Y : Shear Strength, Resolved, Lower Yield	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
2.400e-05	9.100e+06	1.073e+03
5.800e-05	1.080e+07	1.073e+03
5.800e-05	1.180e+07	1.073e+03
1.200e-04	1.340e+07	1.073e+03
1.300e-04	1.390e+07	1.073e+03
2.400e-04	1.650e+07	1.073e+03
5.900e-04	2.540e+07	1.073e+03
2.400e-05	3.800e+06	1.173e+03
6.100e-05	4.900e+06	1.173e+03
1.200e-04	5.600e+06	1.173e+03
2.300e-04	7.900e+06	1.173e+03
5.800e-04	1.110e+07	1.173e+03
6.000e-05	2.700e+06	1.273e+03
1.200e-04	3.300e+06	1.273e+03
2.400e-04	4.100e+06	1.273e+03
5.800e-04	6.300e+06	1.273e+03

Comments on Data

Yield strength increases with increasing stain rate.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A
50, 685-93, 1978.

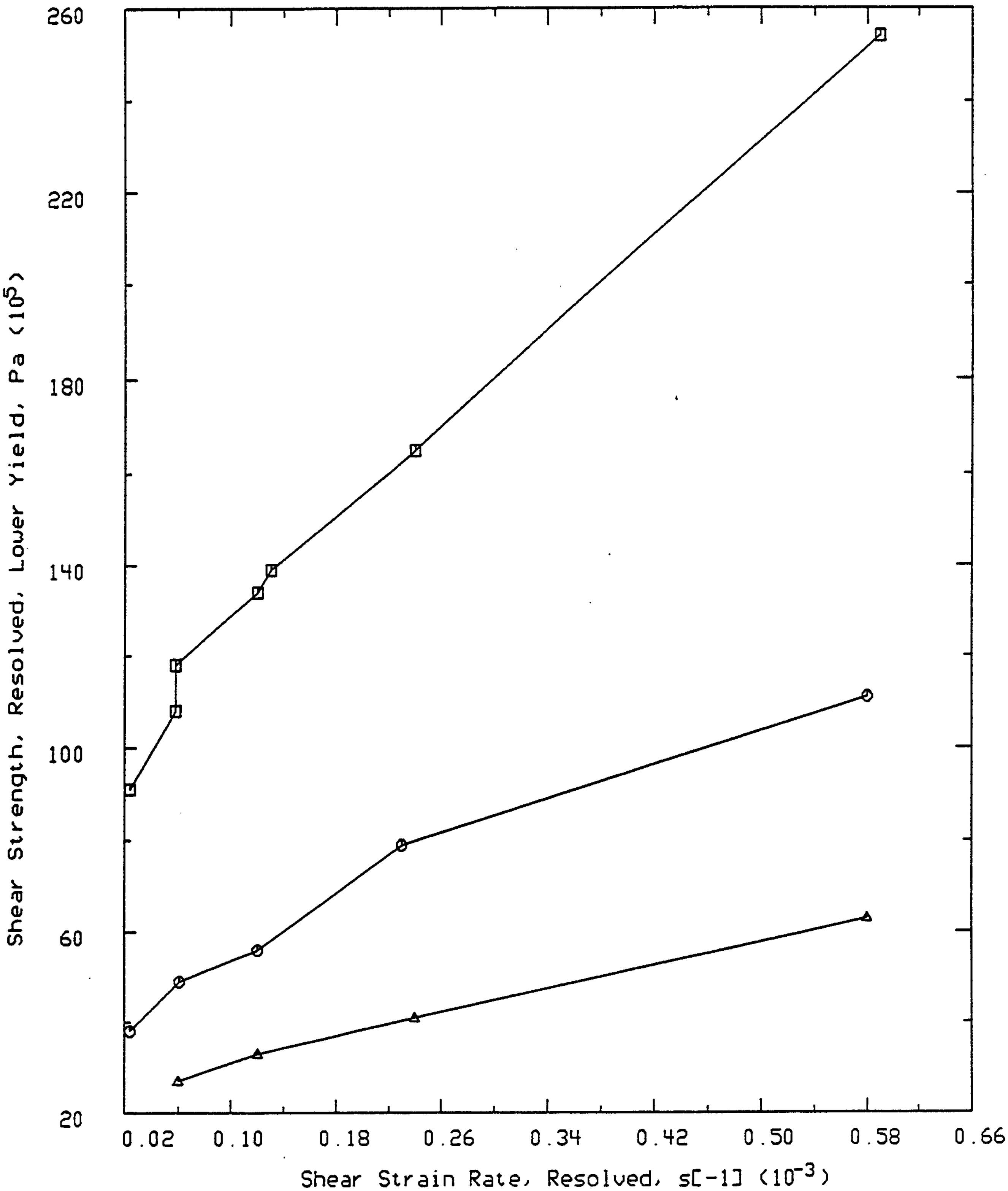

Figure 174 Shear Strength, Resolved, Lower Yield of Silicon, n-type

MATERIAL: Silicon, p-type

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 175

****

Material Preparation

Crystal Growing Method :

Float-zone with grown-in dislocation density

Additional Preparation/Conditioning

Surface Treatment :

Specimens were cut with a diamond saw, lapped with diamond paste and chemically polished.

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	200.-1000.	Ω cm
Temperature	298.	K

Other Properties-Numerical :

Dislocation Density	1.e+04	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

Parameters-Textual :

Deformation carried out under an atmosphere of forming gas (92% N2, 8% H2) or argon in Instron machine using high-temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X Y Z1

1.575e+03	3.200e+06	5.000e-03
1.376e+03	6.400e+06	5.000e-03
1.273e+03	1.070e+07	5.000e-03
1.176e+03	2.060e+07	5.000e-03
1.573e+03	1.400e+06	4.800e-02
1.373e+03	2.900e+06	4.800e-02
1.275e+03	4.700e+06	4.800e-02
1.222e+03	6.000e+06	4.800e-02
1.171e+03	9.100e+06	4.800e-02
1.121e+03	1.300e+07	4.800e-02
1.073e+03	1.850e+07	4.800e-02
1.023e+03	3.080e+07	4.800e-02

Comments on Data

Data was digitized from figure 2
Lower yield behavior of silicon at temperatures between 873 K and the melting point are compatible with results from other authors with dependencies predicted by Haasen's model.

Reference

YIELD POINT AND DISLOCATION MOBILITY IN SILICON AND GERMANIUM.
Schroeter, W. Brion, H. G.
Siethoff, H.
J. APPL. PHYS.
54 (4), 1816-20, 1983.

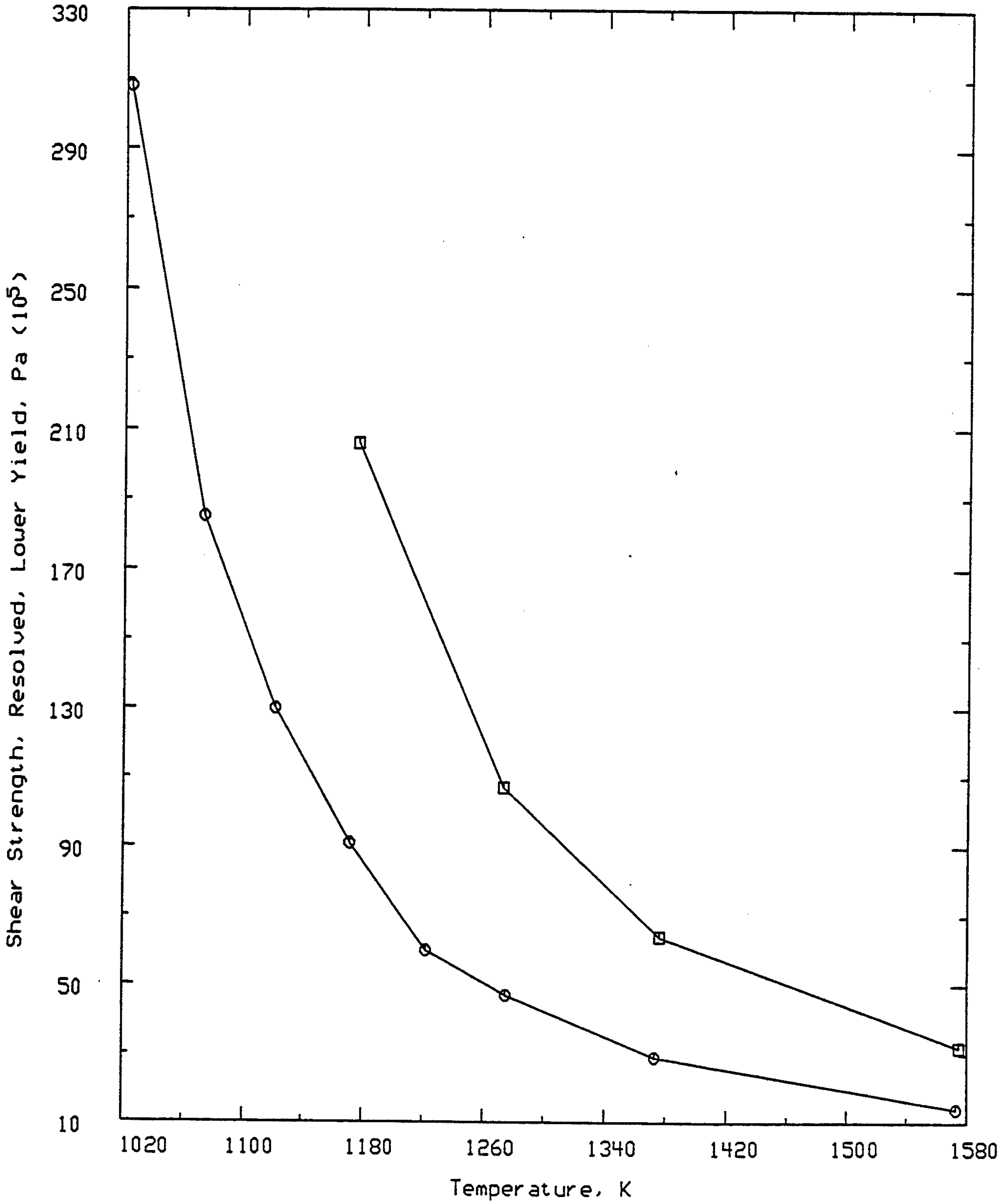

Figure 175 Shear Strength, Resolved, Lower Yield of Silicon, p-type

MATERIAL: Silicon, p-type

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY

PROPERTY: Shear Strength, Resolved, Lower Yield

DATA SET 176

****

Material Preparation

Crystal Growing Method :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	200-1200	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading
High-temperature apparatus mounted to Instron machine. Tests carried under an atmosphere of forming gas (92 pct N_2, 8 pct H_2). Resolved shear properties derived from measured stress-strain curves.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
1.370e+03	2.800e+06	4.770e-04
1.272e+03	4.600e+06	4.770e-04
1.222e+03	5.900e+06	4.770e-04
1.169e+03	8.600e+06	4.770e-04
1.119e+03	1.180e+07	4.770e-04

1.070e+03	1.790e+07	4.770e-04
9.790e+02	3.000e+07	4.770e-04
1.370e+03	2.200e+06	2.390e-04
1.272e+03	3.600e+06	2.390e-04
1.225e+03	4.900e+06	2.390e-04
1.169e+03	6.800e+06	2.390e-04
1.119e+03	9.800e+06	2.390e-04
1.070e+03	1.420e+07	2.390e-04

Comments on Data

Observed results for pure silicon were analyzed by means of dislocation theory. Dislocations move in viscous flow with an activation energy of 2.3 eV.

Reference

THE YIELD POINT OF SILICON AND SILICON-GERMANIUM SOLID SOLUTIONS.
Siethoff, H.
MATER. SCI. ENG.
4, 155-62, 1969.

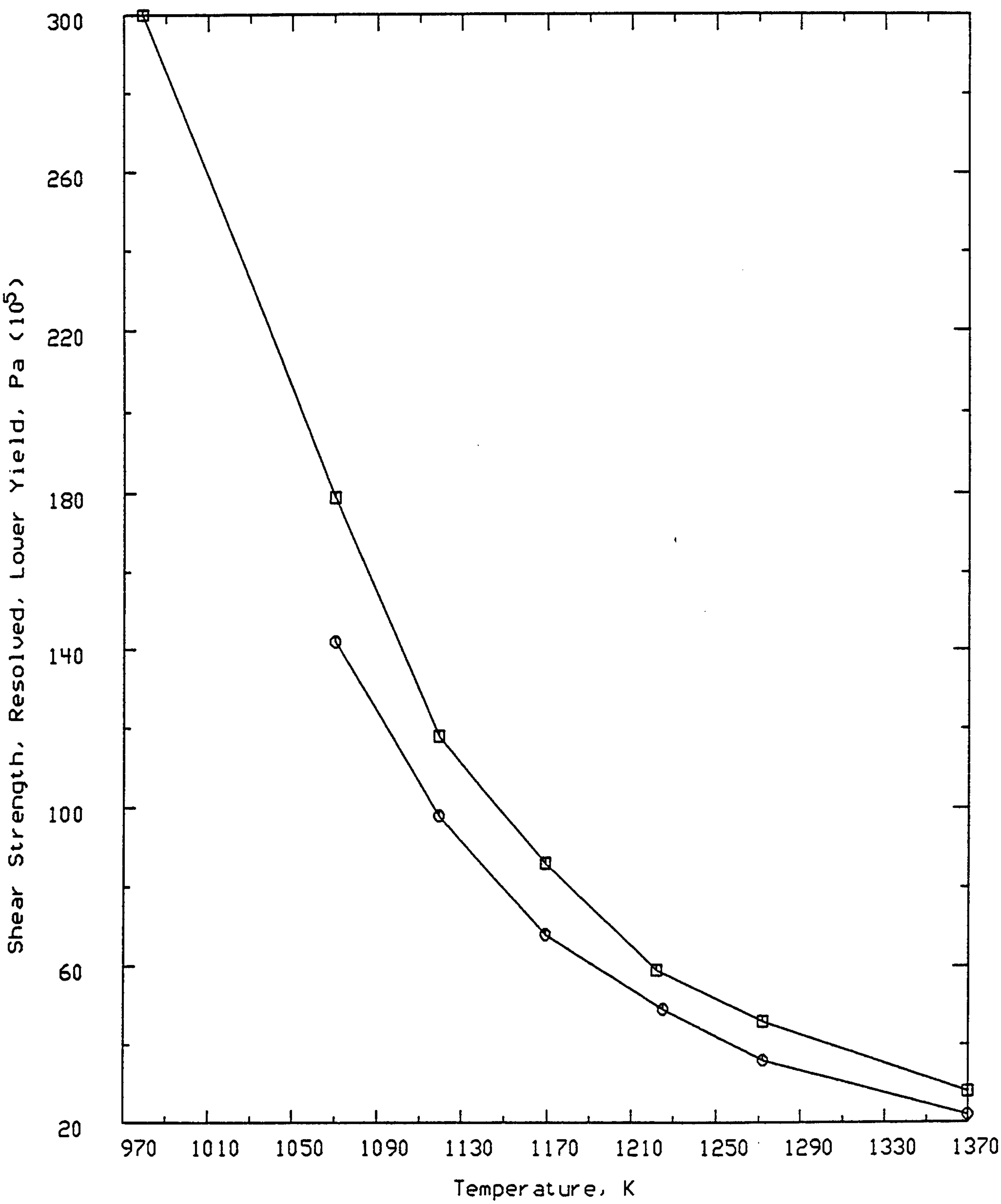

Figure 176 Shear Strength, Resolved, Lower Yield of Silicon, p-type

MATERIAL: Silicon, p-type

PROPERTY: Shear Strength, Resolved, Lower Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 177

****

Material Preparation

Crystal Growing Method :

Float-zone with grown-in dislocation density

Additional Preparation/Conditioning

Surface Treatment :

Specimens were cut with a diamond saw, lapped with diamond paste and chemically polished.

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	200.-1000.	Ω cm
Temperature	298.	K

Other Properties-Numerical :

Dislocation Density	1.e+04	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

Parameters-Textual :

Deformation carried out under an atmosphere of forming gas (92% N2, 8% H2) or argon in Instron machine using high-temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1

1.600e-04	1.700e+06	1.373e+03
1.700e-04	1.800e+06	1.373e+03
1.600e-04	2.000e+06	1.373e+03
7.500e-04	2.700e+06	1.373e+03
2.000e-03	4.400e+06	1.373e+03
4.240e-03	5.000e+06	1.373e+03
9.190e-03	6.200e+06	1.373e+03
2.654e-02	8.800e+06	1.373e+03
3.000e-04	1.100e+06	1.573e+03
6.300e-04	1.300e+06	1.573e+03
8.090e-03	3.200e+06	1.573e+03

Comments on Data

Data was digitized from figure 1
Lower yield stress as a function of strain rate at different temperatures in log-log scale give straight parallel lines.

Reference

YIELD POINT AND DISLOCATION MOBILITY IN SILICON AND GERMANIUM.
Schroeter, W.   Brion, H. G.
Siethoff, H.
J. APPL. PHYS.
54 (4), 1816-20, 1983.

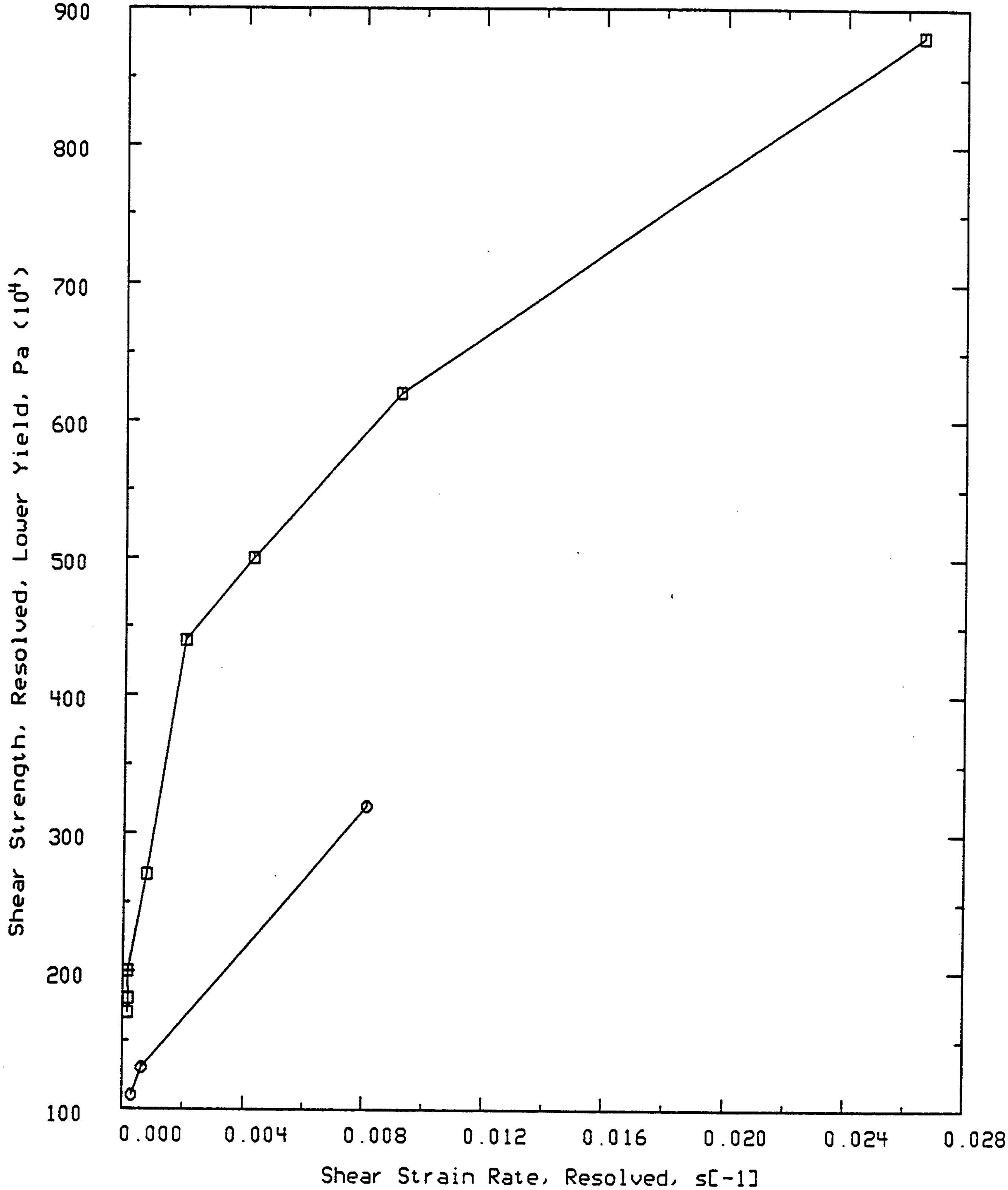

Figure 177 Shear Strength, Resolved, Lower Yield of Silicon, p-type

MATERIAL: Silicon, p-type

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY

PROPERTY: Shear Strength, Resolved, Lower Yield

DATA SET 178

****

Material Preparation

Crystal Growing Method :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	200-1200	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading
High-temperature apparatus mounted to Instron machine. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2). Resolved shear properties derived from measured stress-strain curves.

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Lower Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
2.400e-04	3.700e+06	1.273e+03
5.500e-04	4.800e+06	1.273e+03
1.200e-03	6.600e+06	1.273e+03
2.400e-03	8.200e+06	1.273e+03
4.600e-03	1.100e+07	1.273e+03

1.400e-02	1.520e+07	1.273e+03
1.200e-04	5.300e+06	1.173e+03
2.400e-04	7.400e+06	1.173e+03
4.800e-04	9.200e+06	1.173e+03
1.200e-03	1.270e+07	1.173e+03
2.500e-03	1.640e+07	1.173e+03
4.900e-03	2.030e+07	1.173e+03
1.200e-02	2.820e+07	1.173e+03

Comments on Data

Observed results for pure silicon were analyzed by means of dislocation theory. Dislocations move in viscous flow with an activation energy of 2.3 eV.

Reference

THE YIELD POINT OF SILICON AND SILICON-GERMANIUM SOLID SOLUTIONS.
Siethoff, H.
MATER. SCI. ENG.
4, 155-62, 1969.

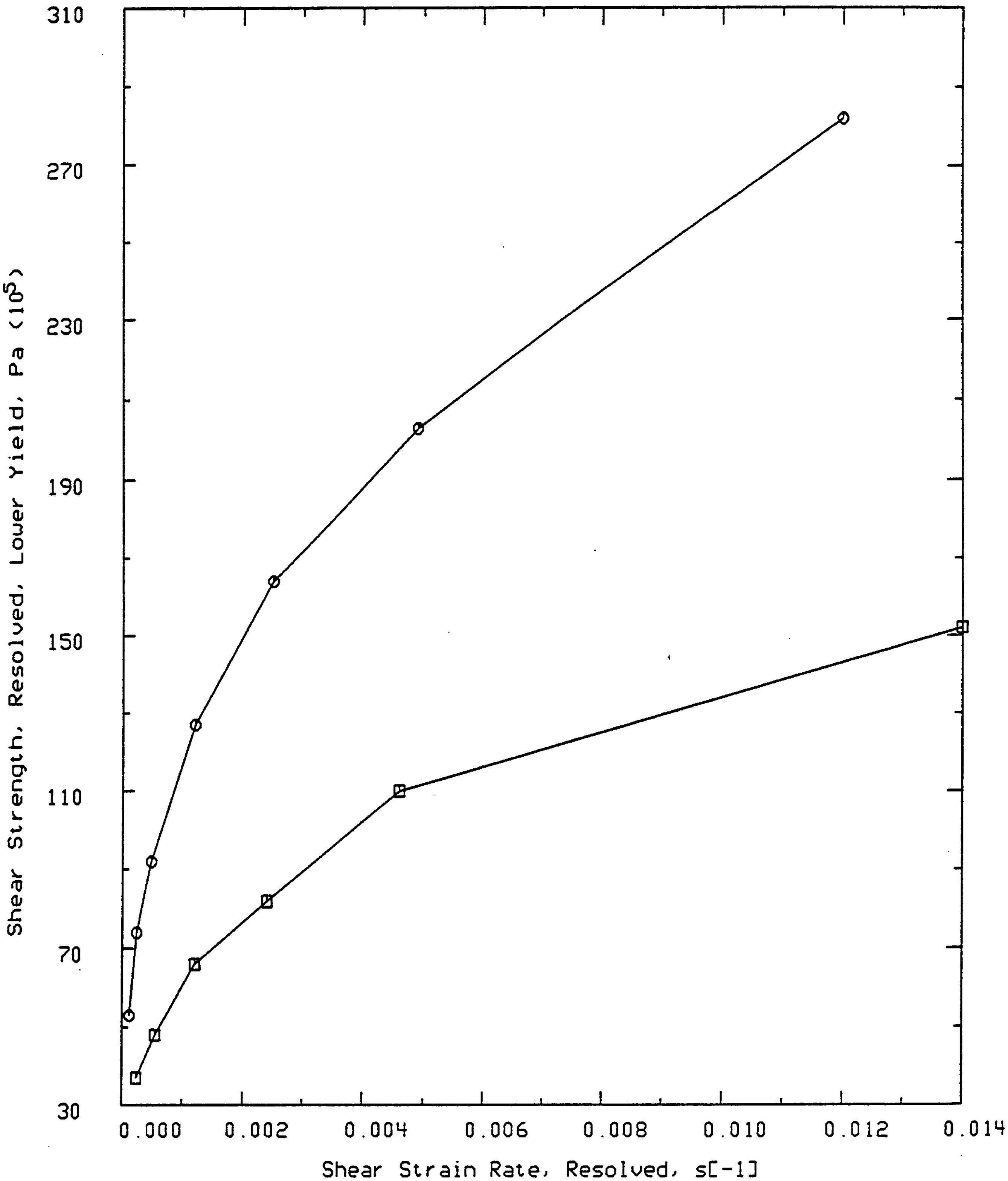

Figure 178 Shear Strength, Resolved, Lower Yield of Silicon, p-type

MATERIAL: Silicon: B doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 179

****

Composition

1.25e20 cm^{-3} Boron Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :
Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Specimens were cut with a diamond saw, lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
4.800e-05	1.610e+07	1.173e+03

1.200e-04	1.670e+07	1.173e+03
2.400e-04	2.660e+07	1.173e+03
4.900e-04	3.480e+07	1.173e+03
1.100e-03	5.120e+07	1.173e+03
2.500e-03	6.450e+07	1.173e+03
1.200e-04	1.010e+07	1.373e+03
2.400e-04	1.270e+07	1.373e+03
4.900e-04	1.220e+07	1.373e+03
1.200e-03	1.660e+07	1.373e+03
2.400e-03	1.790e+07	1.373e+03
5.200e-03	2.740e+07	1.373e+03
1.200e-02	4.030e+07	1.373e+03

Comments on Data

Data was digitizied from Figure 1.
At high strain rates the slope of curves is the same for pure and doped Silicon. The stress exponent of dislocation velocity remains unchanged by doping in this region. At low strain rates the yield point, especially lower yield, is independent of strain rate.

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

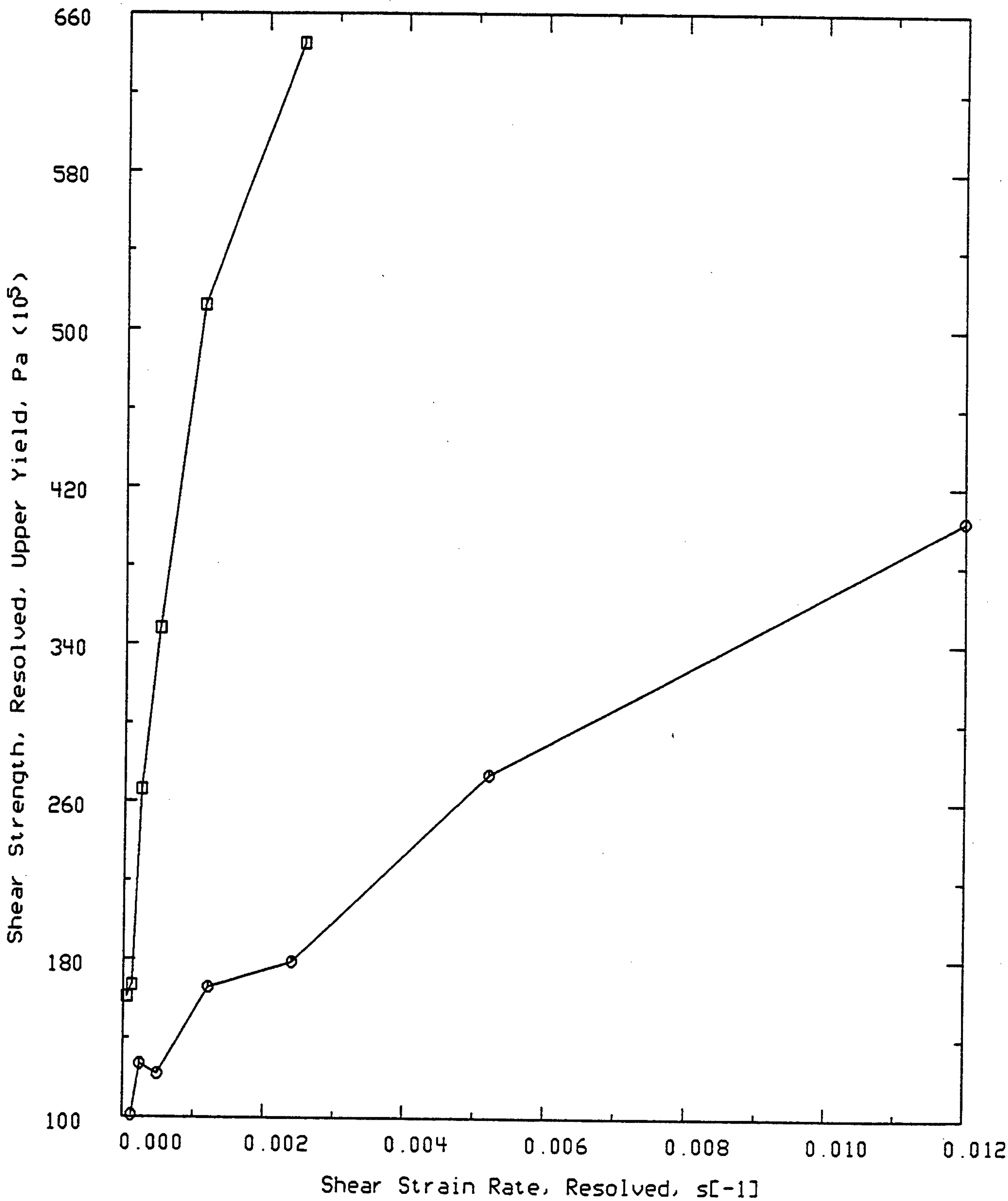

Figure 179 Shear Strength, Resolved, Upper Yield of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Shear Strength, Resolved, Upper Yield

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PURDUE UNIVERSITY
DATA SET 180

****

Composition

4.0e19	cm^{-3}	Boron Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :
Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Specimens were cut with a diamond saw,
lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.

Measured/Evaluated Properties

X : Shear Strain Rate, Resolved	s^{-1}
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1
2.500e-04	2.370e+07	1.173e+03

4.800e-04	3.360e+07	1.173e+03
1.200e-03	5.580e+07	1.173e+03
5.200e-04	1.670e+07	1.273e+03
1.200e-03	2.460e+07	1.273e+03
2.400e-03	2.990e+07	1.273e+03
5.000e-03	4.590e+07	1.273e+03
4.800e-05	3.600e+06	1.373e+03
1.300e-04	5.000e+06	1.373e+03
2.500e-04	7.100e+06	1.373e+03
4.800e-04	8.000e+06	1.373e+03
1.200e-03	9.000e+06	1.373e+03
2.400e-03	1.740e+07	1.373e+03
5.000e-03	2.370e+07	1.373e+03
1.300e-02	3.640e+07	1.373e+03

Comments on Data

Data was digitizied from Figure 2.
At high strain rates the slope of curves is the same for pure and doped Silicon. The stress exponent of dislocation velocity remains unchanged by doping in this region.

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

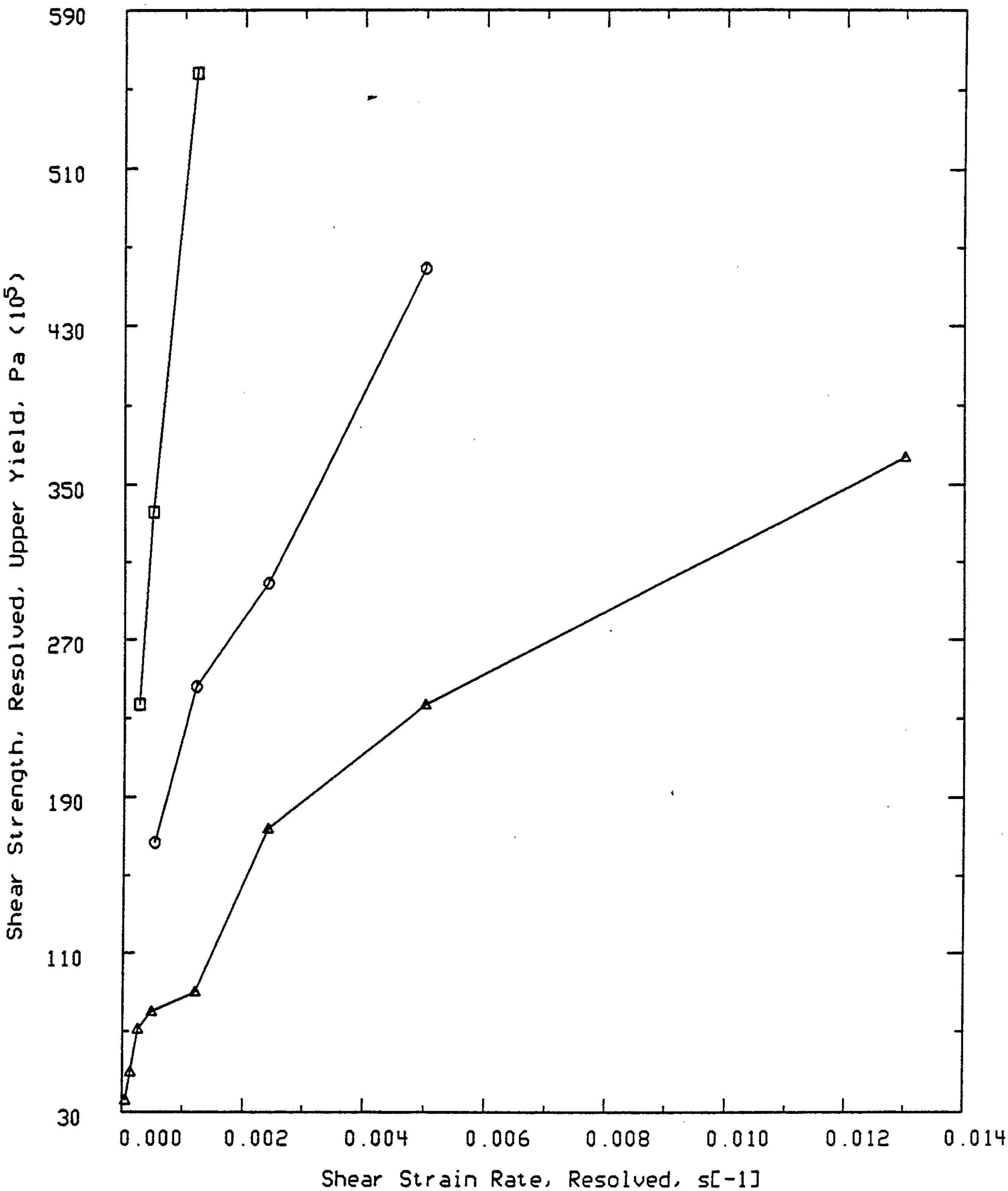

Figure 180 Shear Strength, Resolved, Upper Yield of Silicon: B doped

MATERIAL: Silicon: C doped

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 181

PROPERTY: Shear Strength, Resolved, Upper Yield

****

Composition

6.0e17 cm^{-3} Oxygen Concentration

Vendor/Producer/Fabricator

Sony Corp. and Komatsu Electronic Metals Co.

Material Preparation

Crystal Growing Method :
Czochralski grown
Descriptors-Textual :
Prior to tensile tests all specimens were subjected to annealing at 1573 K for 2 hours followed by rapid cooling at a rate of 150 C per minute to eliminate possible segregation of carbon and/or oxygen, and also to homogenize the distribution of defects.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Other Properties-Numerical :

Dislocation Density	1.0e06	cm^{-2}

Measurement/Evaluation Method

Name/Description :
Shear Response Under Tensile Loading
Tests conducted in vacuum using an Instron machine.
Dislocation density determined by etch-pit technique.
Resolved shear properties derived from recorded data.
Carbon and oxygen concentrations determined by IR absorption.
Parameters-Codified :
Shear Strain Rate, Resolved : 1.1e-04 s[-1]
Pressure : 1.33e-02 pa

Measured/Evaluated Properties

X : Carbon Concentration	m^{-3}
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Temperature	K

Data Points :

X Y Z1

0.000e+00	3.200e+07	1.073e+03
1.700e+23	4.180e+07	1.073e+03
2.500e+23	4.420e+07	1.073e+03
0.000e+00	1.360e+07	1.173e+03
1.700e+23	1.650e+07	1.173e+03
2.500e+23	1.860e+07	1.173e+03

Comments on Data

Carbon results in increase in mechanical strength of silicon crystals if it coexists with oxygen concentrations higher than 5.0e17 atoms/cm[3]. Upper yield stress increases monotonically with increase in carbon concentration.

Reference

ROLE OF CARBON IN THE STRENGTHENING OF SILICON CRYSTALS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS., PART 2
23 (8), 590-2, 1984.

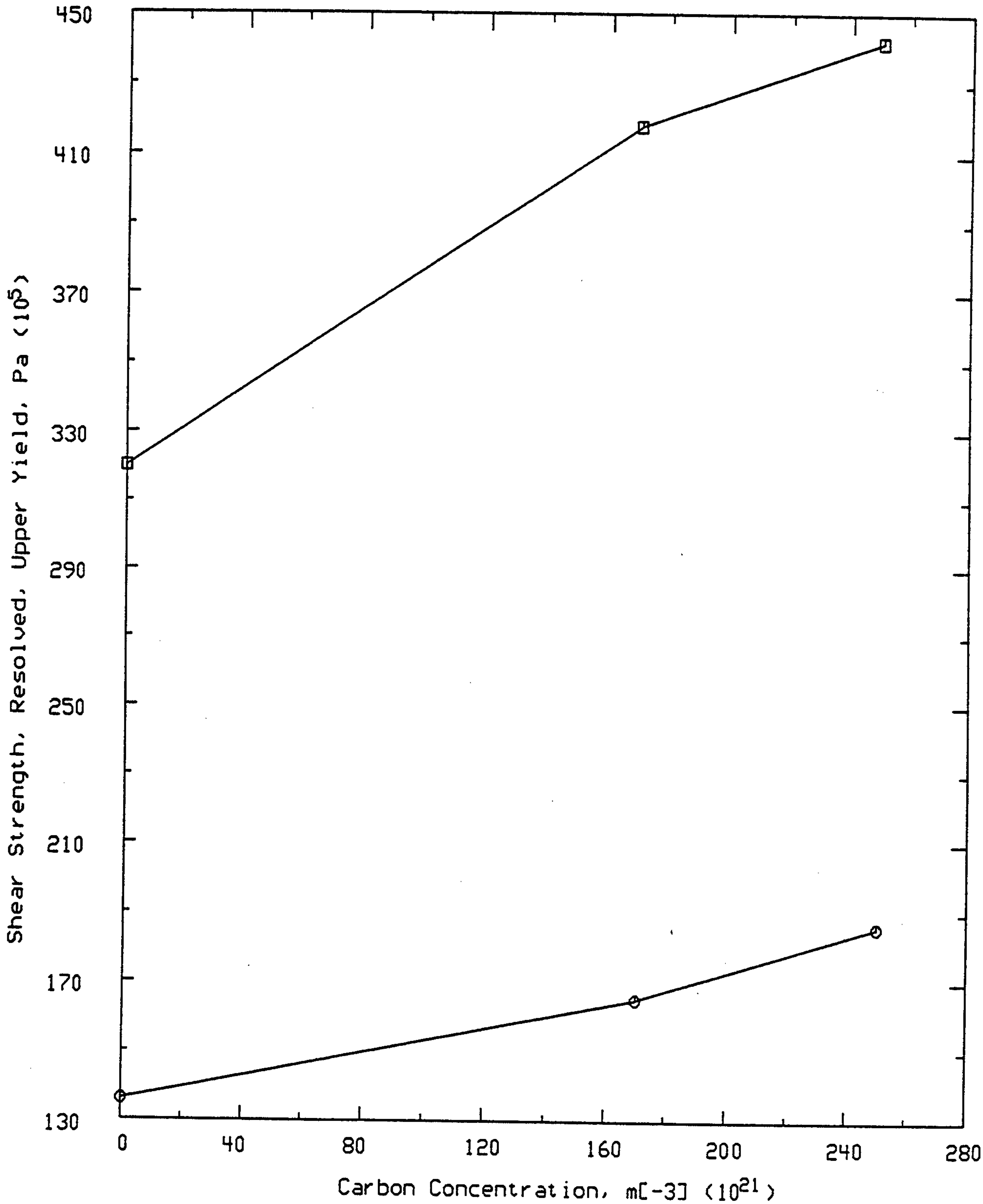

Figure 181 Shear Strength, Resolved, Upper Yield of Silicon: C doped

MATERIAL: Silicon: C doped

PROPERTY: Shear Strength, Resolved, Upper Yield

****

Composition

1.7e17	cm^{-3}	Carbon Concentration
1.5e17	cm^{-3}	Oxygen Concentration

Vendor/Producer/Fabricator

Sony Corp. and Komatsu Electronic Metals Co.

Material Preparation

Crystal Growing Method :

Float-zone grown

Descriptors-Textual :

Prior to tensile tests all specimens were subjected to annealing at 1573 K for 2 hours followed by rapid cooling at a rate of 150 C per minute to eliminate possible segregation of carbon and/or oxygen, and also to homogenize the distribution of defects.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading
Tests conducted in vacuum using an Instron machine.
Dislocation density determined by etch-pit technique.
Resolved shear properties derived from recorded data.
Carbon and oxygen concentrations determined by IR absorption.

Parameters-Codified :

Shear Strain Rate, Resolved : 1.1e-04 s[-1]
Pressure : 1.33e-02 pa

Measured/Evaluated Properties

X	: Dislocation Density	m^{-2}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
8.600e+07	3.520e+07	1.073e+03
4.000e+08	3.220e+07	1.073e+03
1.500e+09	2.160e+07	1.073e+03

1.300e+10	1.150e+07	1.073e+03
8.200e+07	1.460e+07	1.173e+03
3.900e+08	9.900e+06	1.173e+03
1.300e+10	3.800e+06	1.173e+03

Comments on Data

The upper yield strength increases with a decrease in dislocation density. At 1073 K effect is more profound as compared to 1173 K Results show that carbon atoms dissolved in a silicon crystal have little effect in locking dislocations by themselves without the presence of oxygen atoms.

Reference

ROLE OF CARBON IN THE STRENGTHENING OF SILICON CRYSTALS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS., PART 2
23 (8), 590-2, 1984.

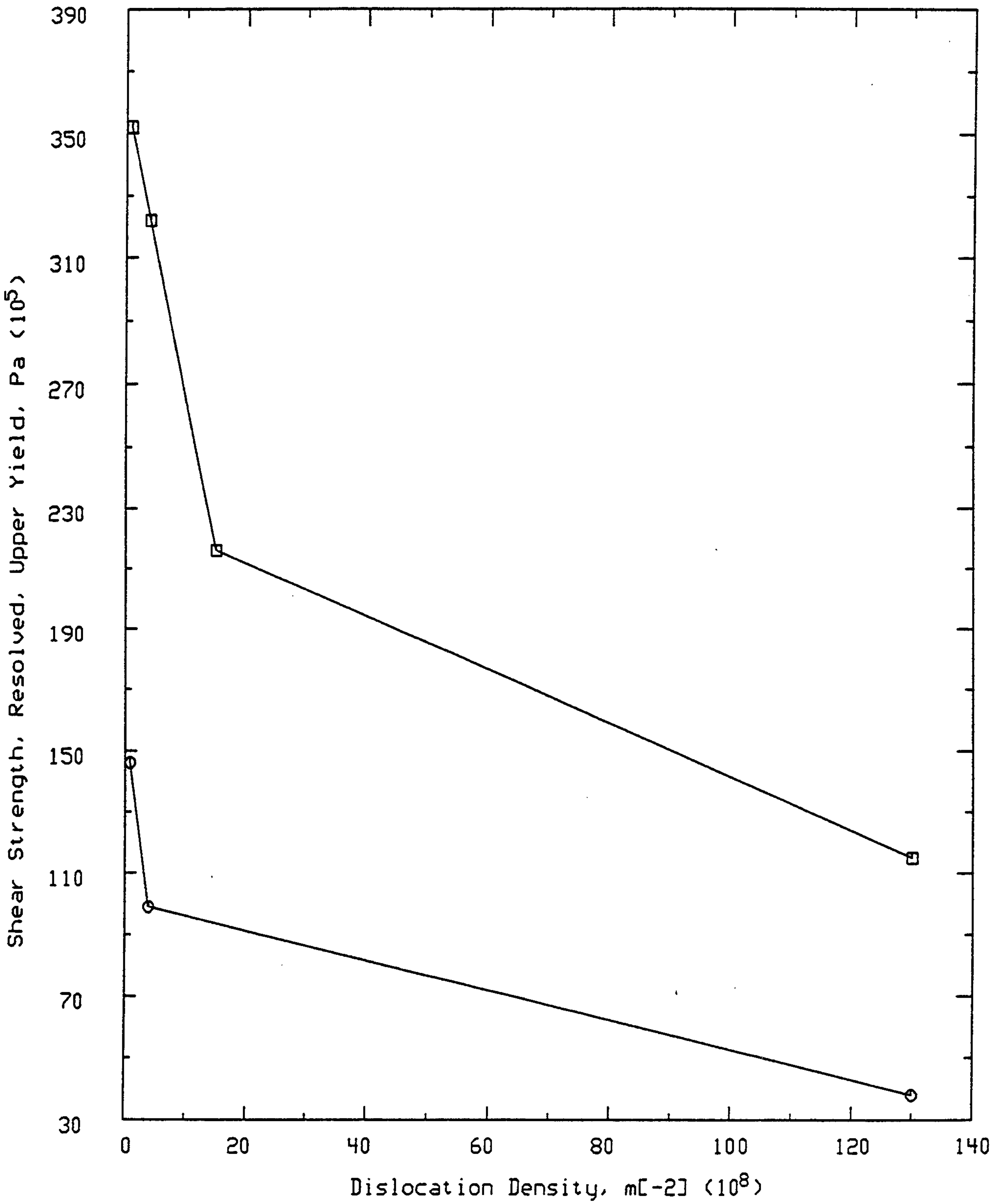

Figure 182 Shear Strength, Resolved, Upper Yield of Silicon: C doped

MATERIAL: Silicon: O doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 183

****

Composition

1.5e17 cm^{-3} Oxygen Concentration

Vendor/Producer/Fabricator

Sony Corp. and Komatsu Electronic Metals Co.

Material Preparation

Crystal Growing Method :

Float-zone grown

Descriptors-Textual :

Prior to tensile tests all specimens were subjected to annealing at 1573 K for 2 hours followed by rapid cooling at a rate of 150 C per minute to eliminate possible segregation of carbon and/or oxygen, and also to homogenize the distribution of defects.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading
Tests conducted in vacuum using an Instron machine.
Dislocation density determined by etch-pit technique.
Resolved shear properties derived from recorded data.
Carbon and oxygen concentrations determined by IR absorption.

Parameters-Codified :

Shear Strain Rate, Resolved : 1.1e-04 s[-1]
Pressure : 1.33e-02 pa

Measured/Evaluated Properties

X : Dislocation Density m^{-2}
Y : Shear Strength, Resolved, Upper Yield Pa
Z1 : Temperature K

Data Points :

X	Y	Z1
1.600e+08	3.110e+07	1.073e+03
2.000e+08	3.160e+07	1.073e+03
6.300e+08	2.130e+07	1.073e+03
2.000e+09	1.580e+07	1.073e+03

2.400e+09	1.320e+07	1.073e+03
9.000e+09	9.600e+06	1.073e+03
1.000e+10	1.070e+07	1.073e+03
1.700e+10	8.800e+06	1.073e+03
2.000e+10	1.070e+07	1.073e+03
1.600e+08	9.000e+06	1.173e+03
2.000e+08	1.050e+07	1.173e+03
1.700e+09	5.000e+06	1.173e+03
3.600e+09	4.600e+06	1.173e+03
1.300e+10	3.400e+06	1.173e+03
1.700e+10	3.800e+06	1.173e+03

Comments on Data

Results show that mobility of dislocations in a silicon crystal does not appear to be influenced by oxygen atoms.
Magnitude of yield strength of carbon-doped differs very little from oxygen-doped.

Reference

ROLE OF CARBON IN THE STRENGTHENING OF SILICON CRYSTALS.
Yonenaga, I.   Sumino, K.
JPN. J. APPL. PHYS., PART 2
23 (8), 590-2, 1984.

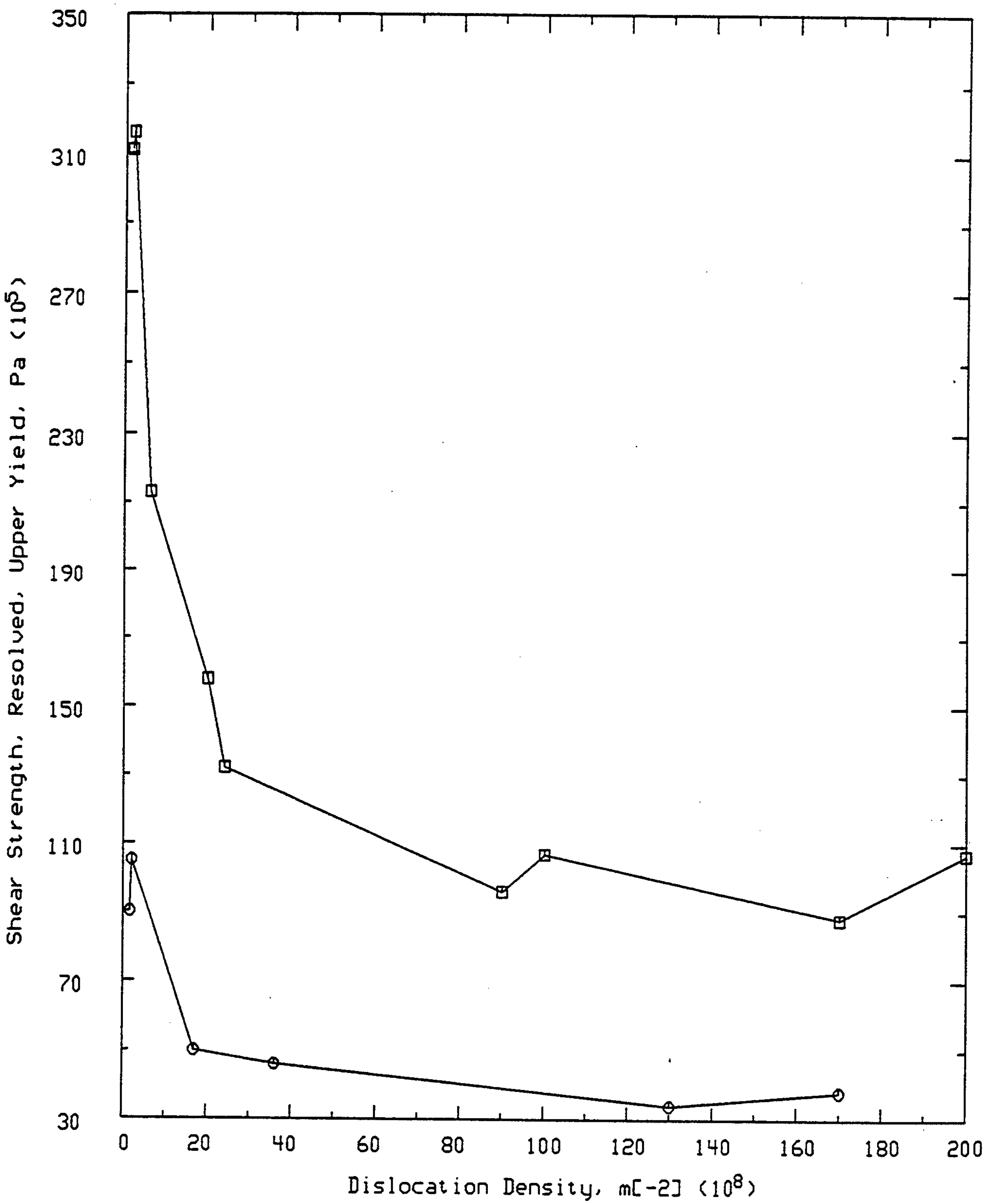

Figure 183 Shear Strength, Resolved, Upper Yield of Silicon: O doped

MATERIAL: Silicon: O doped HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield DATA SET 184
****

Composition
1.5e17 cm^{-3} Oxygen Concentration

Vendor/Producer/Fabricator
Sony Corp. and Komatsu Electronic Metals Co.

Material Preparation
Crystal Growing Method :
Czochralski grown
Descriptors-Textual :
Prior to tensile tests all specimens were subjected to annealing at 1573 K for 2 hours followed by rapid cooling at a rate of 150 C per minute to eliminate possible segregation of carbon and/or oxygen, and also to homogenize the distribution of defects.

Specimen Identification
Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method
Name/Description :
Shear Response Under Tensile Loading
Tests conducted in vacuum using an Instron machine.
Dislocation density determined by etch-pit technique.
Resolved shear properties derived from recorded data.
Carbon and oxygen concentrations determined by IR absorption.
Parameters-Codified :
Shear Strain Rate, Resolved : 1.1e-04 s[-1]
Pressure : 1.33e-02 pa

Measured/Evaluated Properties
X : Dislocation Density m^{-2}
Y : Shear Strength, Resolved, Upper Yield Pa
Z1 : Temperature K

Data Points :

X	Y	Z1
2.000e+08	4.660e+07	1.073e+03
1.000e+09	3.310e+07	1.073e+03
5.100e+09	2.270e+07	1.073e+03
1.200e+10	1.780e+07	1.073e+03

8.000e+08	1.250e+07	1.173e+03
3.000e+09	8.500e+06	1.173e+03
1.200e+10	5.300e+06	1.173e+03

Comments on Data

Upper yield strength of Czochralski grown silicon is much higher than those of float zone both undoped and doped with carbon.

Reference

ROLE OF CARBON IN THE STRENGTHENING OF SILICON CRYSTALS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS., PART 2
23 (8), 590-2, 1984.

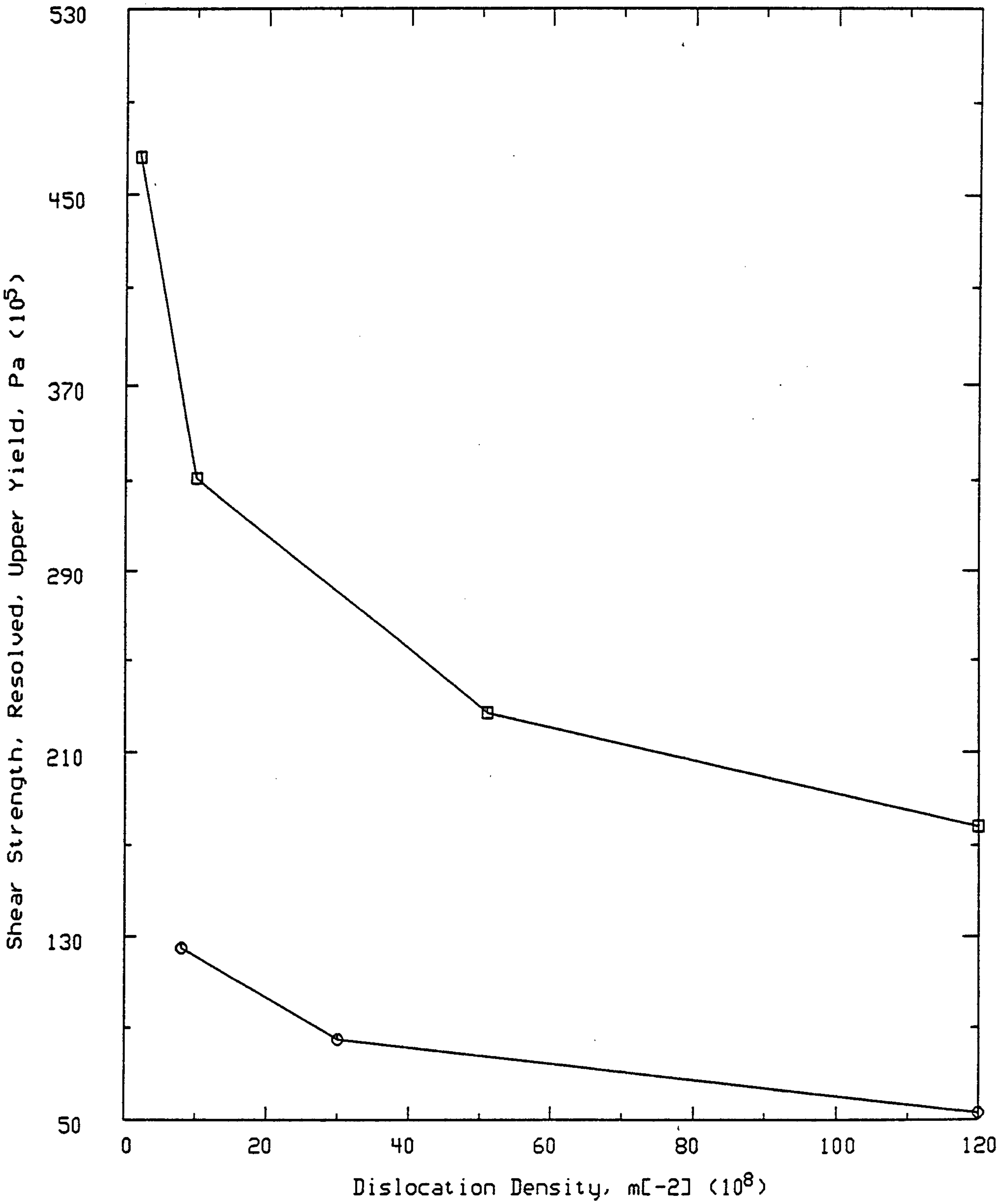

Figure 184 Shear Strength, Resolved, Upper Yield of Silicon: O doped

MATERIAL: Silicon: O doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 185

****

Vendor/Producer/Fabricator

Sony Corp. and Komatsu Electronic Metals Co.

Material Preparation

Crystal Growing Method :

Czochralski grown

Descriptors-Textual :

Prior to tensile tests all specimens were subjected to annealing at 1573 K for 2 hours followed by rapid cooling at a rate of 150 C per minute to eliminate possible segregation of carbon and/or oxygen, and also to homogenize the distribution of defects.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Other Properties-Numerical :

Dislocation Density	1.0e06	cm^{-2}

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading
Tests conducted in vacuum using an Instron machine.
Dislocation density determined by etch-pit technique.
Resolved shear properties derived from recorded data.
Carbon and oxygen concentrations determined by IR absorption.

Parameters-Codified :

Shear Strain Rate, Resolved : 1.1e-04 s[-1]
Pressure : 1.33e-02 pa

Measured/Evaluated Properties

X	: Oxygen Concentration	m^{-3}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K
Z2	: Carbon Concentration	m^{-3}

Data Points :

X	Y	Z1	Z2
5.700e+23	4.450e+07	1.073e+03	2.500e+23

5.600e+23	1.920e+07	1.173e+03	2.500e+23
0.000e+00	1.180e+07	1.073e+03	1.700e+23
2.400e+23	1.990e+07	1.073e+03	1.700e+23
5.400e+23	4.240e+07	1.073e+03	1.700e+23
0.000e+00	5.400e+06	1.173e+03	1.700e+23
2.400e+23	6.200e+06	1.173e+03	1.700e+23
5.500e+23	1.390e+07	1.173e+03	1.700e+23
5.500e+23	1.640e+07	1.173e+03	1.700e+23
8.300e+23	5.200e+07	1.073e+03	9.000e+22
8.400e+23	2.000e+07	1.173e+03	9.000e+22

Comments on Data

Carbon content has no effect on dislocation-free crystal.
Upper yield strength increases distinctly by presence of carbon if crystal contains oxygen at concentration above 5.0e17 atoms/cm[3].
Carbon content has almost no influence on upper yield strength when oxygen content is below 4.0e17 atoms/cm[3].

Reference

ROLE OF CARBON IN THE STRENGTHENING OF SILICON CRYSTALS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS., PART 2
23 (8), 590-2, 1984.

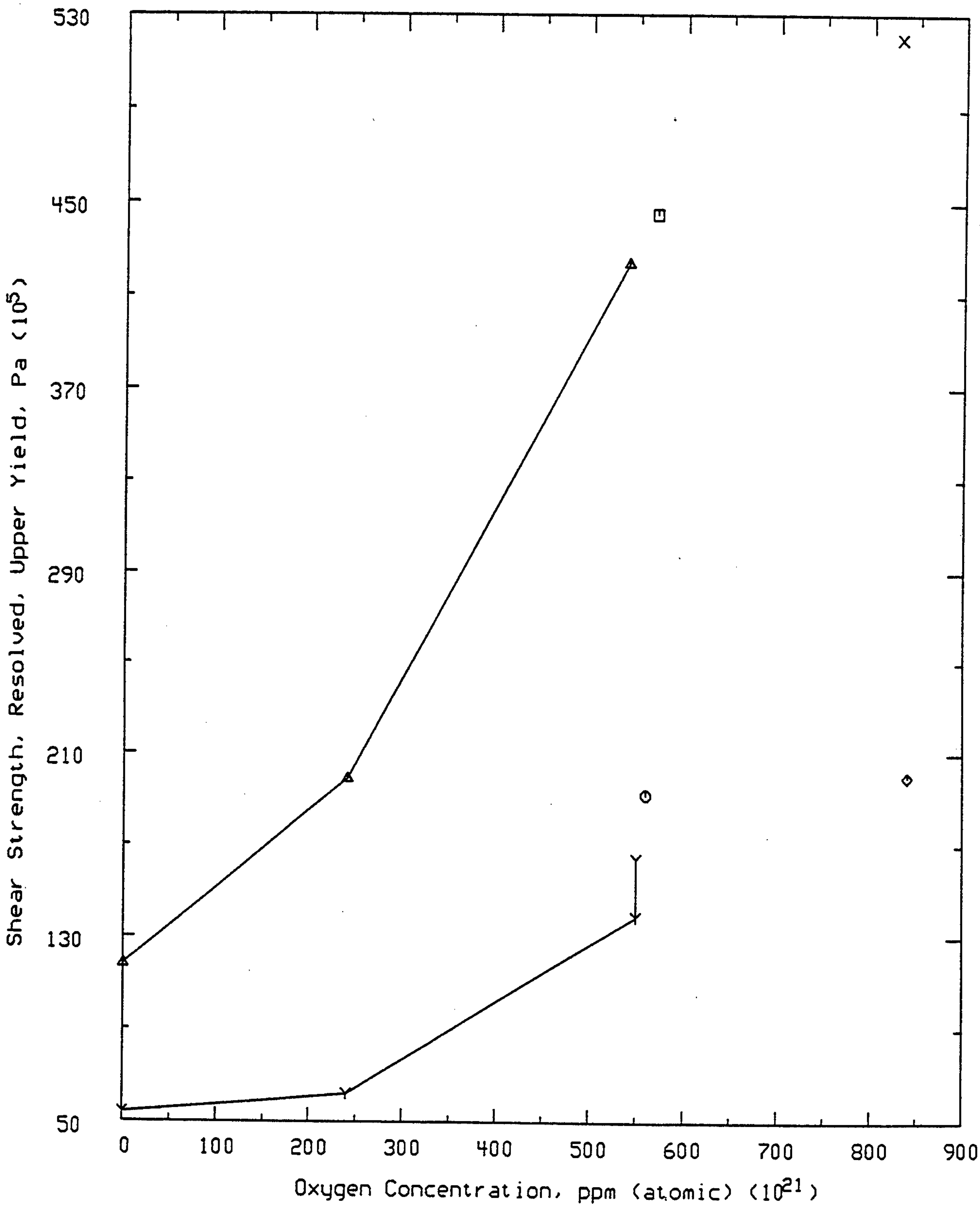

Figure 185 Shear Strength, Resolved, Upper Yield of Silicon: O doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 186

****

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Material Preparation

Crystal Growing Method :
Floating zone, p-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :
Specimens were cut with a diamond saw,
lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction
Additional Identifiers :
Orientation suitable for single slip

Measurement/Evaluation Method

Name/Description :
Compression Loaded Bar Method
Deformation carried out at constant strain rates under an atmosphere of forming gas (92 percent N2, 8 percent H2) or argon in Instron machine using high temperature compression apparatus. Accuracy of temperature measurement was +/- 1 K.
Parameters-Codified :
Shear Strain Rate, Resolved : 4.8e-03 s[-1]

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Phosphorus Dopant Concentration	m^{-3}

Data Points :

X	Y	Z1
1.372e+03	1.960e+07	5.000e+25
1.322e+03	2.520e+07	5.000e+25

1.273e+03	3.640e+07	5.000e+25
1.224e+03	4.860e+07	5.000e+25
1.175e+03	7.010e+07	5.000e+25

Comments on Data

Activation energy for P-doped Silicon was found to be 2.0 eV as compared to 2.3 eV for pure Silicon.

Reference

THE EFFECT OF CHARGED IMPURITIES ON THE YIELD POINT OF SILICON.
Siethoff, H.
PHYS. STATUS SOLIDI
40 (1), 153-61, 1970.

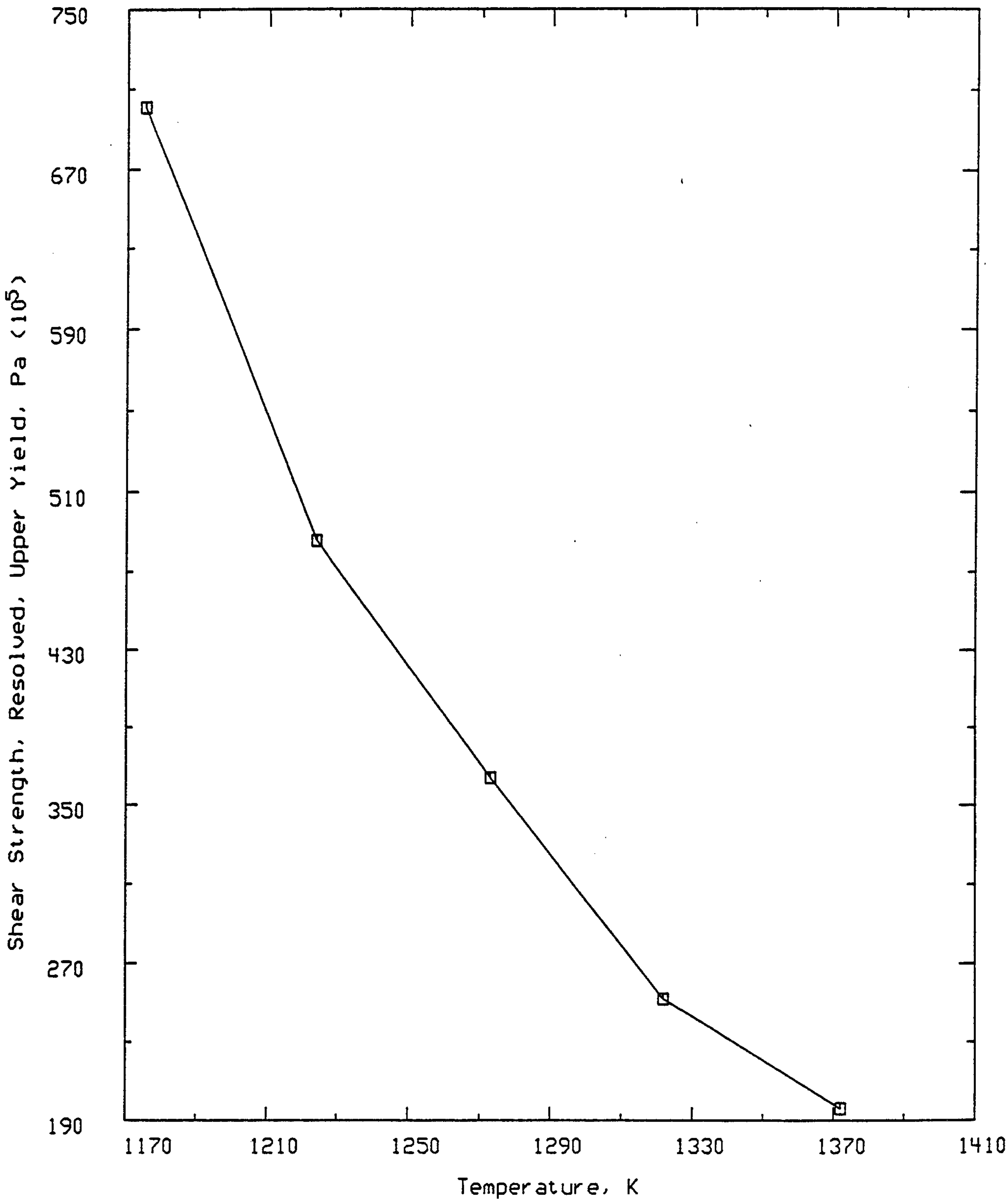

Figure 186 Shear Strength, Resolved, Upper Yield of Silicon: P doped

MATERIAL:	Silicon: P doped	HTMIAC/CINDAS 1994 PURDUE UNIVERSITY
PROPERTY:	Shear Strength, Resolved, Upper Yield	DATA SET 187

****

Composition

2.5e14	cm^{-3}	Phosphorus Dopant Concentration
1.0e16	cm^{-3}	Carbon Concentration
1.3e16	cm^{-3}	Oxygen Concentration

Material Preparation

Crystal Growing Method :

Float-zone grown, n-type, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

Chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.	mm
Thickness	3.	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Slip system along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	16.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Testing machine not specified, probably Instron machine.
Resolved shear properties derived from measured stress-strain curves.

Parameters-Codified :

Pressure : 1.e-06 torr

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Remarks:
1.107e+03	2.894e+07	1.450e-04	smoothed data
1.140e+03	2.150e+07	1.450e-04	
1.174e+03	1.565e+07	1.450e-04	
1.208e+03	1.118e+07	1.450e-04	
1.247e+03	8.300e+06	1.450e-04	
1.287e+03	6.280e+06	1.450e-04	
1.314e+03	5.150e+06	1.450e-04	
1.106e+03	1.390e+07	4.750e-05	smoothed data
1.141e+03	1.055e+07	4.750e-05	
1.174e+03	7.800e+06	4.750e-05	
1.210e+03	6.180e+06	4.750e-05	
1.248e+03	4.770e+06	4.750e-05	
1.288e+03	3.760e+06	4.750e-05	
1.314e+03	3.200e+06	4.750e-05	

Comments on Data

A graph of log yield strength vs. 1/T yield parallel straight lines which is in agreement with the dislocation theory.

Reference

PLASTIC DEFORMATION OF SILICON MONOCRYSTALS OF DIFFERENT BASIC DISLOCATIONS DENSITY IN THE YIELD POINT REGION.
Doerschel, J.   Kirscht, F. G.
Baehr, R.
KRIST. TECH.
12 (11), 1191-200, 1977.

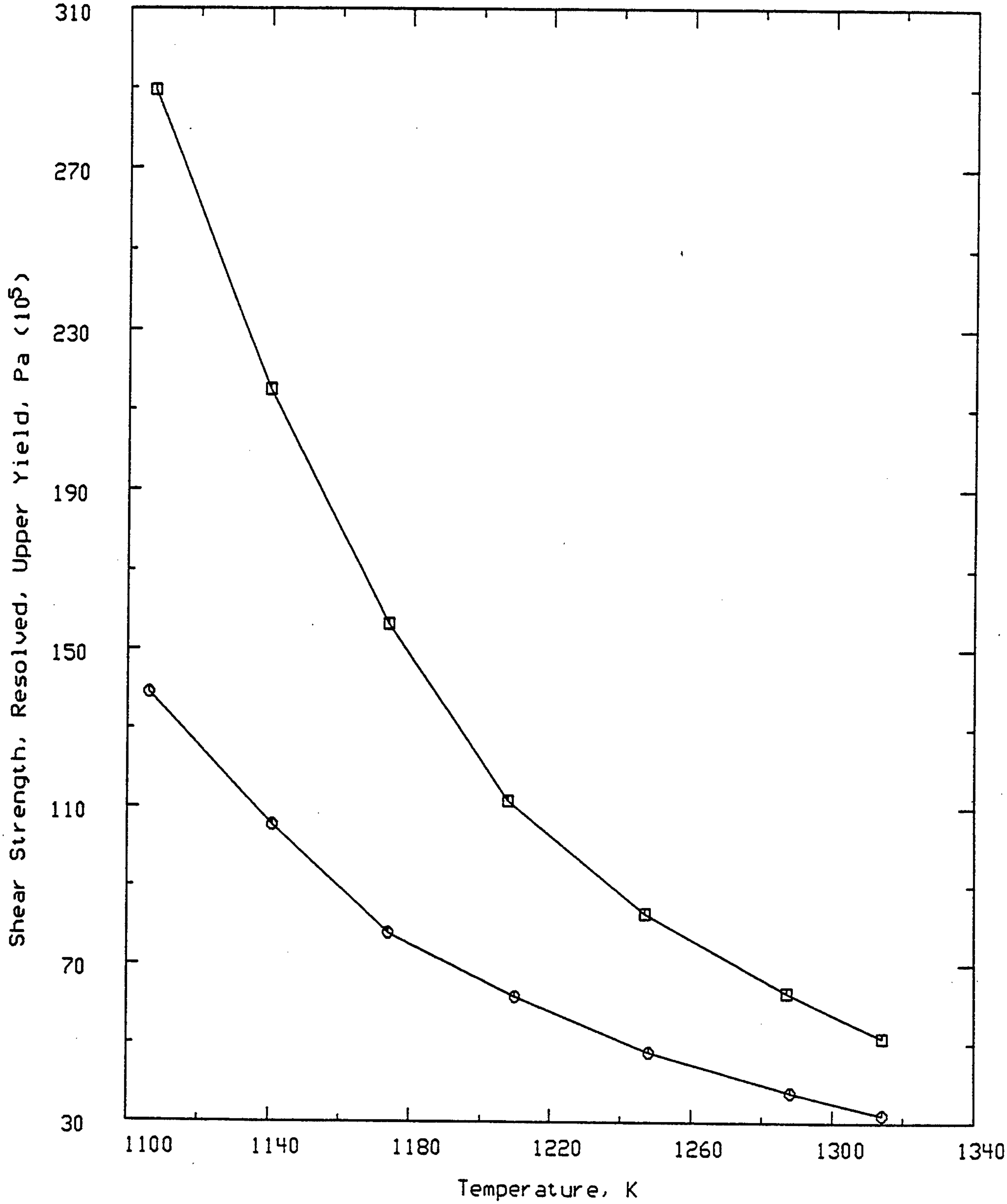

Figure 187 Shear Strength, Resolved, Upper Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 188

****

Composition

1.7e13	cm^{-3}	Phosphorus Dopant Concentration
1.0e16	cm^{-3}	Carbon Concentration
8.0e15	cm^{-3}	Oxygen Concentration

Material Preparation

Crystal Growing Method :

Float-zone grown, n-type, grown-in dislocation density

Additional Preparation/Conditioning

Surface Treatment :

Chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.	mm
Thickness	3.	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Slip system along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	250.	Ω cm
Temperature	298.	K

Other Properties-Numerical :

Dislocation Density	6.5e04	cm^{-2}

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Testing machine not specified, probably Instron machine.
Resolved shear properties derived from measured stress-strain curves.

Parameters-Codified :

Pressure : 1.e-06 torr

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Upper Yield	Pa

Z1 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1	Remarks:
1.107e+03	1.507e+07	1.450e-04	smoothed data
1.141e+03	1.143e+07	1.450e-04	
1.174e+03	8.480e+06	1.450e-04	
1.210e+03	6.430e+06	1.450e-04	
1.248e+03	5.070e+06	1.450e-04	
1.288e+03	3.830e+06	1.450e-04	
1.314e+03	3.270e+06	1.450e-04	
1.108e+03	8.170e+06	4.750e-05	smoothed data
1.141e+03	6.190e+06	4.750e-05	
1.210e+03	3.550e+06	4.750e-05	
1.248e+03	2.750e+06	4.750e-05	
1.287e+03	2.120e+06	4.750e-05	
1.315e+03	1.810e+06	4.750e-05	

Comments on Data

Grown-in dislocation density lowers the yield strength as compared to dislocation-free crystals.
Log yield strength vs. 1/T gave parallel straight lines which is in agreement with the dislocation theory.

Reference

PLASTIC DEFORMATION OF SILICON MONOCRYSTALS OF DIFFERENT BASIC DISLOCATIONS DENSITY IN THE YIELD POINT REGION.
Doerschel, J. Kirscht, F. G.
Baehr, R.
KRIST. TECH.
12 (11), 1191-200, 1977.

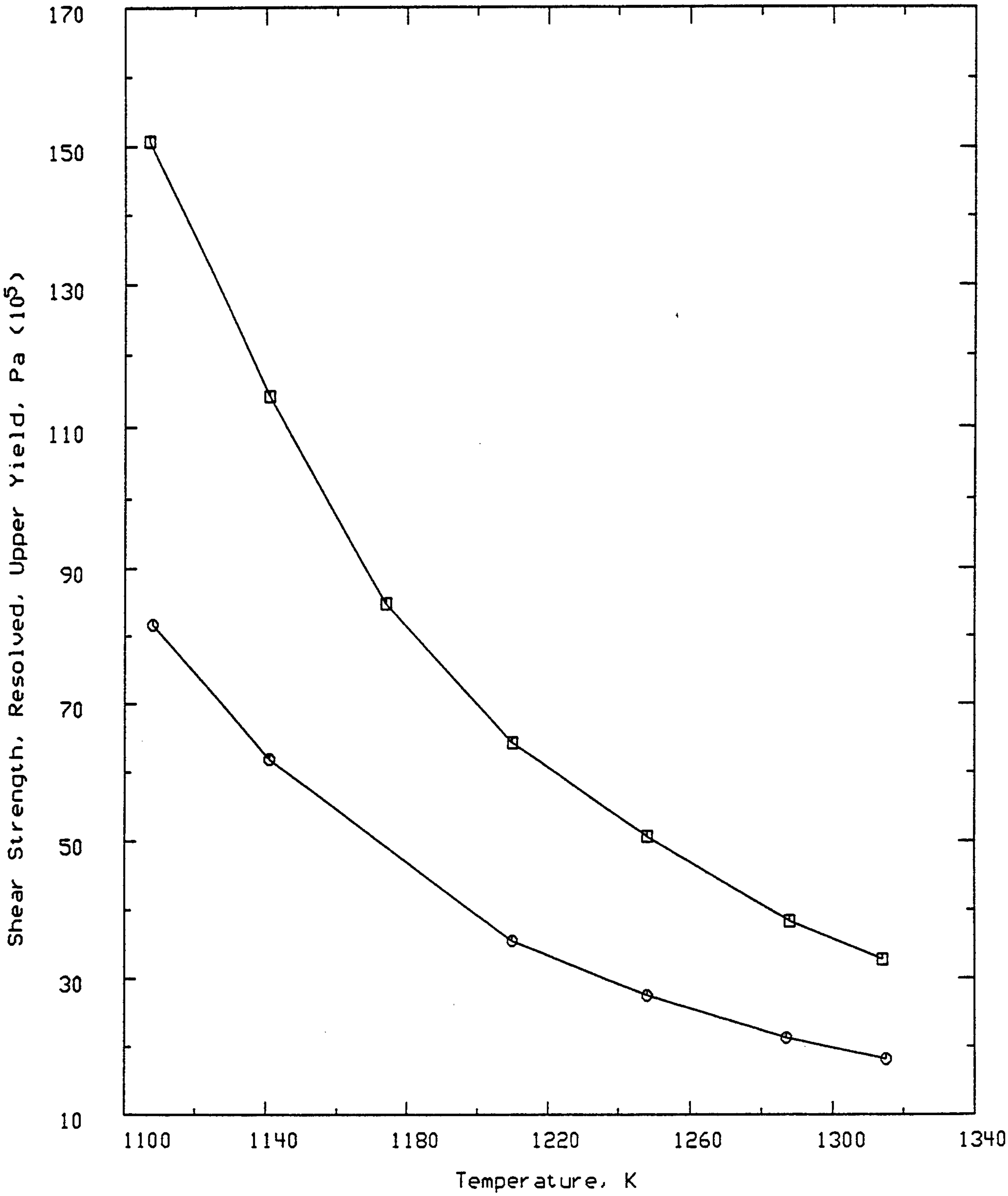

Figure 188 Shear Strength, Resolved, Upper Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 189

****

Composition

1.0e20 cm^{-3} Phosphorus Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Coating Description :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished
Specimens were cut with a diamond saw.

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Instron machine mounted to a high-temperature apparatus. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2).

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
1.370e+03	2.060e+07	4.770e-03
1.318e+03	2.490e+07	4.770e-03
1.265e+03	3.300e+07	4.770e-03
1.218e+03	4.140e+07	4.770e-03
1.370e+03	1.670e+07	2.390e-03
1.267e+03	2.730e+07	2.390e-03

1.167e+03	4.230e+07	2.390e-03
1.369e+03	9.700e+06	4.770e-04
1.320e+03	1.190e+07	4.770e-04
1.269e+03	1.410e+07	4.770e-04
1.222e+03	1.940e+07	4.770e-04
1.169e+03	2.310e+07	4.770e-04
1.118e+03	2.800e+07	4.770e-04
1.070e+03	3.930e+07	4.770e-04
1.018e+03	5.630e+07	4.770e-04
1.369e+03	8.300e+06	2.390e-04
1.269e+03	1.260e+07	2.390e-04
1.169e+03	1.920e+07	2.390e-04
1.070e+03	3.190e+07	2.390e-04

Comments on Data

A graph of log yield strength vs. 1/T yields straight lines of slopes different than the ones obtained for pure silicon.

Reference

THE INITIAL STAGE OF PLASTIC DEFORMATION OF SILICON HIGHLY DOPED WITH PHOSPHORUS.
Siethoff, H.
ACTA METALL.
17, 793-801, 1969.

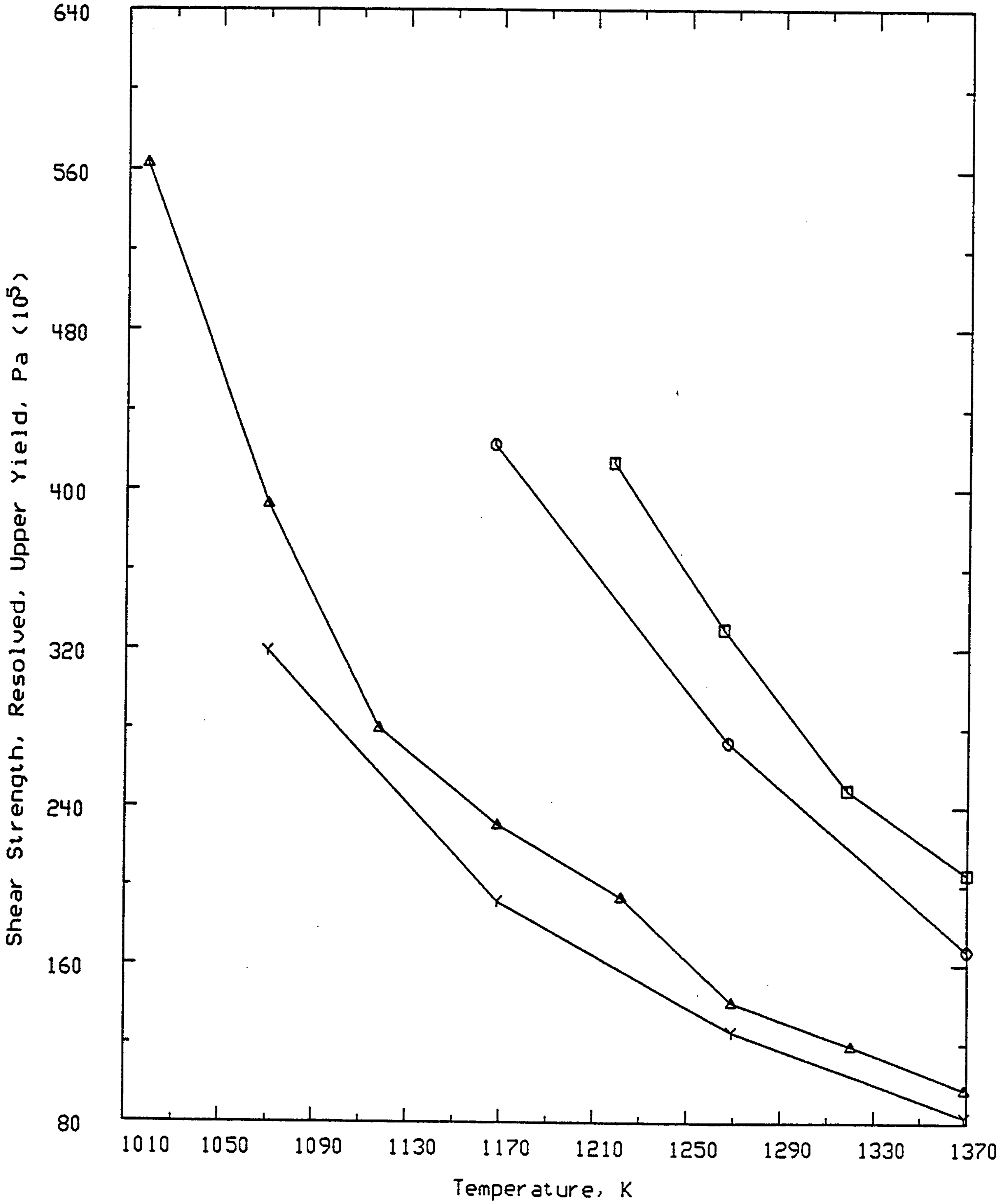

Figure 189 Shear Strength, Resolved, Upper Yield of Silicon: P doped

MATERIAL: Silicon: P doped | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield | DATA SET 190

****

Composition

1.0e20 cm^{-3} Phosphorus Dopant Concentration

Vendor/Producer/Fabricator

Wacker Chemie, Munchen

Coating Description :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished
Specimens were cut with a diamond saw.

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Measurement/Evaluation Method

Name/Description :

Compression Loaded Bar Method
Instron machine mounted to a high-temperature apparatus. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2).

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
2.500e-04	2.030e+07	1.173e+03
4.900e-04	2.370e+07	1.173e+03
1.300e-03	3.330e+07	1.173e+03
2.500e-03	4.670e+07	1.173e+03
1.300e-04	1.000e+07	1.273e+03
2.500e-04	1.240e+07	1.273e+03

4.900e-04	1.450e+07	
1.300e-03	1.860e+07	
2.600e-03	2.690e+07	
4.900e-03	3.230e+07	
1.200e-02	4.970e+07	
2.500e-02	6.370e+07	
2.500e-04	8.600e+06	1.373e+03
4.900e-04	9.400e+06	
2.400e-03	1.640e+07	
4.900e-03	2.100e+07	
1.300e-02	2.780e+07	

Comments on Data

Upper yield strength of the heavily doped crystals showed marked deviations from that of pure and low doped crystals over the range of stain rates studied. Behavior interpreted as solid solution hardening due to electrostatic interaction between dislocations and solute atoms.

Reference

THE INITIAL STAGE OF PLASTIC DEFORMATION OF SILICON HIGHLY DOPED WITH PHOSPHORUS.
Siethoff, H.
ACTA METALL.
17, 793-801, 1969.

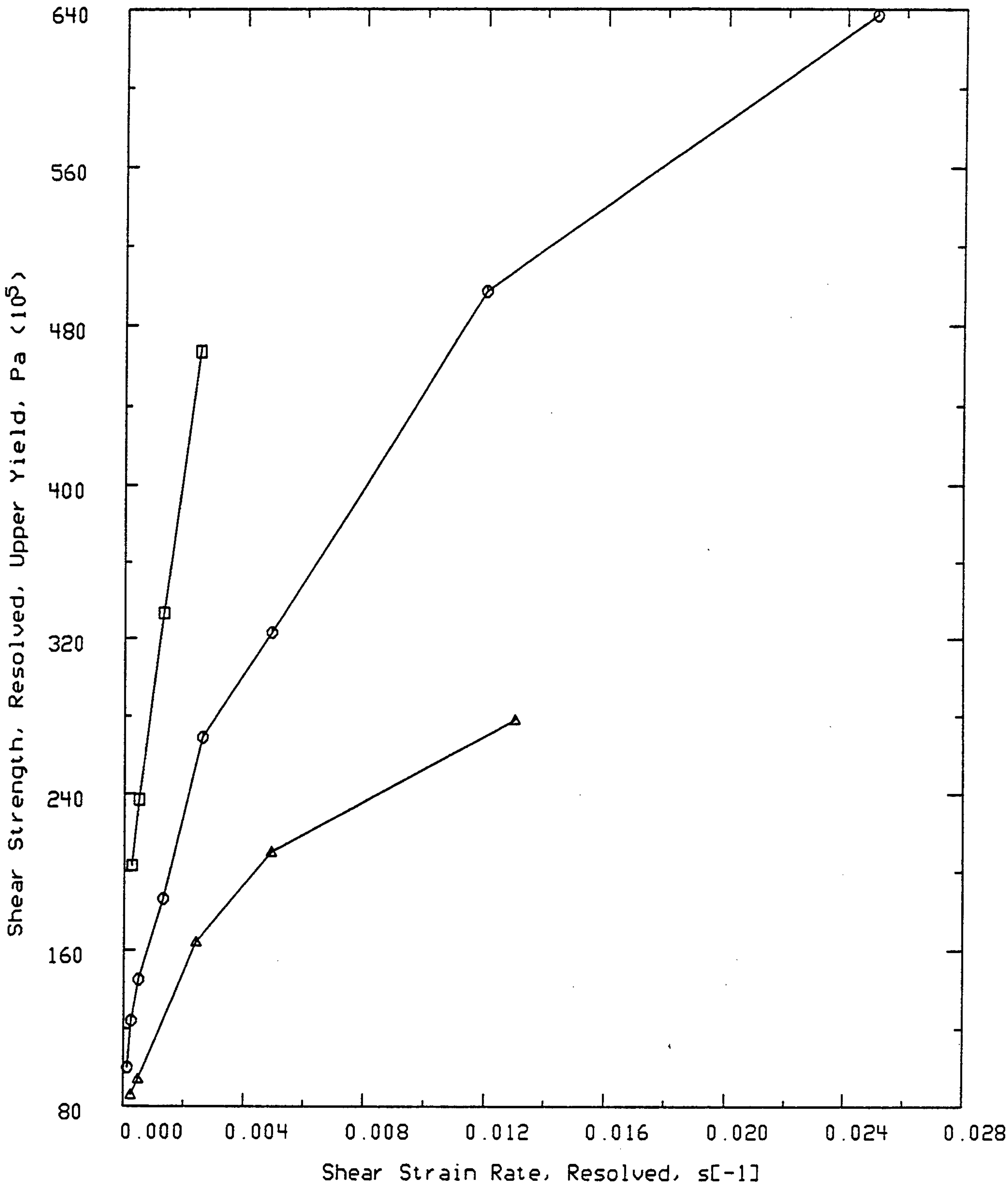

Figure 190 Shear Strength, Resolved, Upper Yield of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 191

****

Composition

1.e18	cm^{-3}	Oxygen Concentration
2.e16	cm^{-3}	Carbon Concentration

Vendor/Producer/Fabricator

KOFU Works of Hitachi Ltd.

Material Preparation

Crystal Growing Method :
Czochralski grown, dislocation free, n-type
Grown with diameter of 76 mm in the [111] direction.
Descriptors-Textual :
Annealed at 1323. K for various times.

Additional Preparation/Conditioning

Surface Treatment :
Surface layers polished and removed to depth more than 250 microns.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	7-9	Ω cm
Temperature	298	K

Measurement/Evaluation Method

Name/Description :
Shear Response Under Tensile Loading
Test conducted in vacuum using Instrom machine mounted to high temperature apparatus. Resolved shear properties derived from measured data.
Parameters-Codified :
Pressure : 1.e-05 Torr
Shear Strain, Resolved : 1.1e-04 s[-1]
Temperature : 1173. K
Annealing Temperature : 1323. K

Measured/Evaluated Properties

X : Annealing Time s

Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Annealing Temperature	K
Z2	: Temperature	K
Z3	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2	Z3
0.000e+00	3.540e+07	1.323e+03	1.173e+03	1.100e-04
8.496e+03	3.290e+07	1.323e+03	1.173e+03	1.100e-04
8.532e+03	2.700e+07	1.323e+03	1.173e+03	1.100e-04
2.070e+04	1.030e+07	1.323e+03	1.173e+03	1.100e-04
4.169e+04	7.500e+06	1.323e+03	1.173e+03	1.100e-04
8.474e+04	7.100e+06	1.323e+03	1.173e+03	1.100e-04
1.710e+05	9.300e+06	1.323e+03	1.173e+03	1.100e-04

Comments on Data

Yield strength decreased drastically with annealing time in the range of 0 to 10 hours; longer annealing time did not significantly reduce yield strength.

Reference

MECHANICAL BEHAVIOR OF CZOCHRALSKI-SILICON CRYSTALS AS AFFECTED BY PRECIPITATION AND DISSOLUTION OF OXYGEN ATOMS.
Yonenaga, I. Sumino, K.
JPN. J. APPL. PHYS.
21 (1), 47-55, 1982.

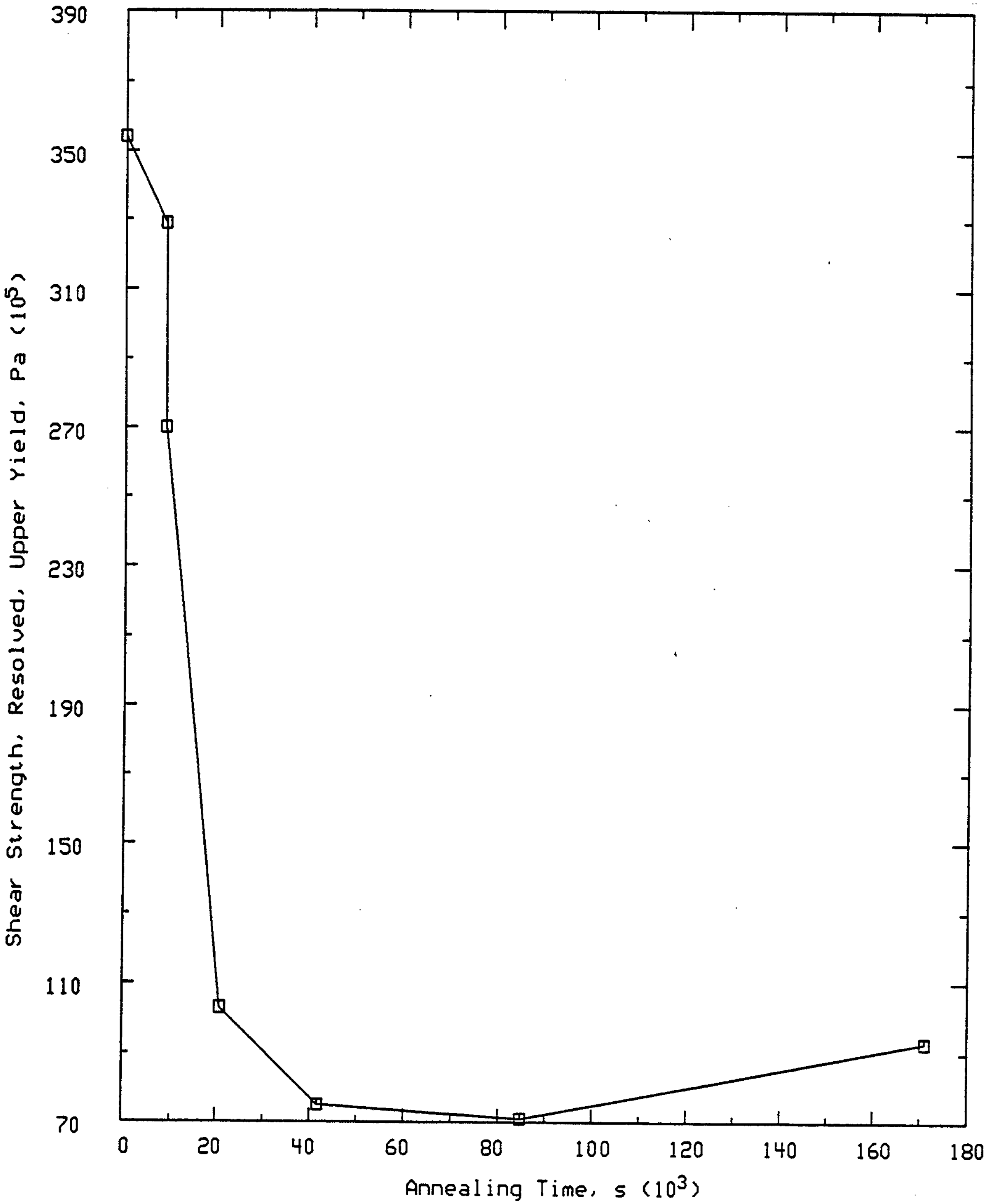

Figure 191 Shear Strength, Resolved, Upper Yield of Silicon: P doped

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Vendor/Producer/Fabricator

Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation

Crystal Growing Method :
Float-zone technique
Crystal grown in a high purity argon gas atmosphere.
Descriptors-Textual :
Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :		
Electrical Resistivity	460.	Ω cm
Temperature	298.	K
Other Properties-Numerical :		
Dislocation Density	2.0e04	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Shear Response Under Tensile Loading
Parameters-Textual :
Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.
Parameters-Codified :
Pressure : 1.3e-02 Pa

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment
Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Upper Yield	Pa

Z1 : Shear Strain Rate, Resolved s^{-1}

Data Points :

X	Y	Z1
1.073e+03	6.000e+07	6.000e-04
1.073e+03	4.810e+07	6.000e-04
1.173e+03	1.950e+07	6.000e-04
1.176e+03	2.120e+07	6.000e-04
1.268e+03	6.600e+06	6.000e-04
1.073e+03	3.130e+07	1.200e-04
1.073e+03	2.950e+07	1.200e-04
1.122e+03	1.510e+07	1.200e-04
1.173e+03	8.600e+06	1.200e-04
1.222e+03	4.500e+06	1.200e-04
1.268e+03	3.800e+06	1.200e-04

Comments on Data

A graph of log yield strength vs. 1/T gave straight lines with an activation energy of 1.25 eV.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A
50, 685-93, 1978.

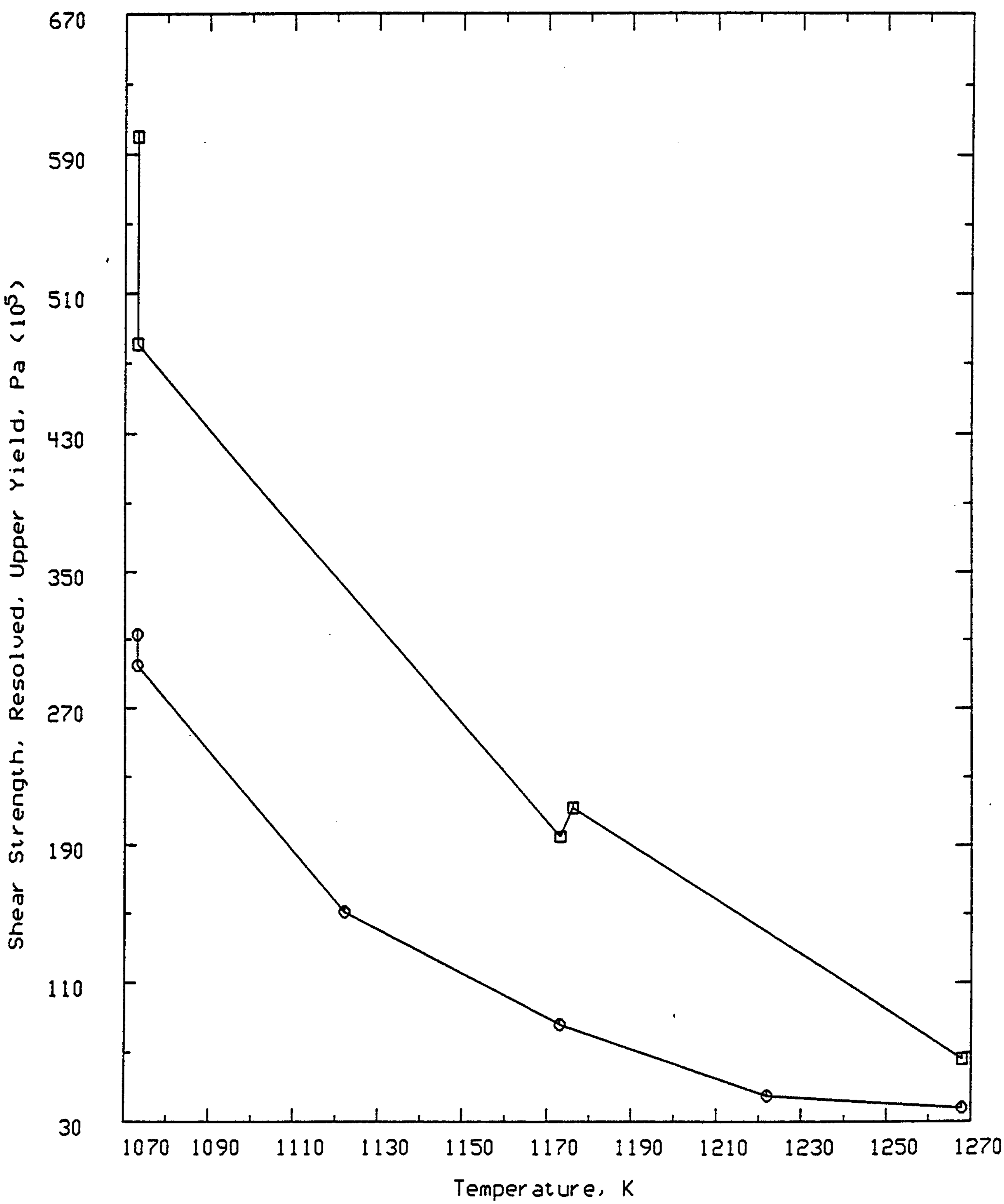

Figure 192 Shear Strength, Resolved, Upper Yield of Silicon, n-type

MATERIAL: Silicon, n-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield	DATA SET 193

****

Vendor/Producer/Fabricator

Wacker

Material Preparation

Crystal Growing Method :

Float-zone grown, dislocation-free

Additional Preparation/Conditioning

Surface Treatment :

{111} and {541} side faces cut with a diamond saw and diamond polished (1/4 micron)

Specimen Identification

Dimensions (Geometry) :

Length	14.	mm
Thickness	4.25	mm
Width	4.25	mm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Specimen oriented to obtain a single slip deformation along {111} planes and <101> directions

Additional Properties

Electrical Properties :

Electrical Resistivity	>5.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading

High-temperature compression stage apparatus mounted on an Instron machine. A continuous flow of forming gas (10 pct. H(2), 90 pct. N(2)) maintained during each test. Curves of resolved shear stress - strain derived from the recorded data.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
9.770e+02	3.820e+07	2.000e-05
1.000e+03	3.420e+07	2.000e-05
1.026e+03	1.810e+07	2.000e-05
1.078e+03	1.020e+07	2.000e-05
1.128e+03	6.400e+06	2.000e-05
1.177e+03	4.200e+06	2.000e-05
1.227e+03	3.600e+06	2.000e-05
1.279e+03	3.400e+06	2.000e-05
1.330e+03	3.000e+06	2.000e-05
1.126e+03	2.490e+07	2.000e-04
1.178e+03	1.100e+07	2.000e-04
1.227e+03	9.000e+06	2.000e-04
1.274e+03	4.800e+06	2.000e-04
1.329e+03	4.000e+06	2.000e-04

Comments on Data

At the lower strain rate, the temperature dependence consists of three stages. The low-temperature range in which the yield strength decreases rapidly with increasing temperature followed from about 1170 - 1320 K by a plateau where it remains constant or even slightly increases with temperature. At higher temperatures the flow stress extrapolated from stage I of easy glide decreases again. At higher strain rate the plateau no longer appears.

Reference

ON THE YIELD POINT OF FLOATING-ZONE SILICON SINGLE CRYSTALS. I. YIELD STRESSES AND ACTIVATION PARAMETERS.
Omri, M. Tete, C. Michel, J. P.
George, A.
PHILOS. MAG. A
55 (5), 601-16, 1987.

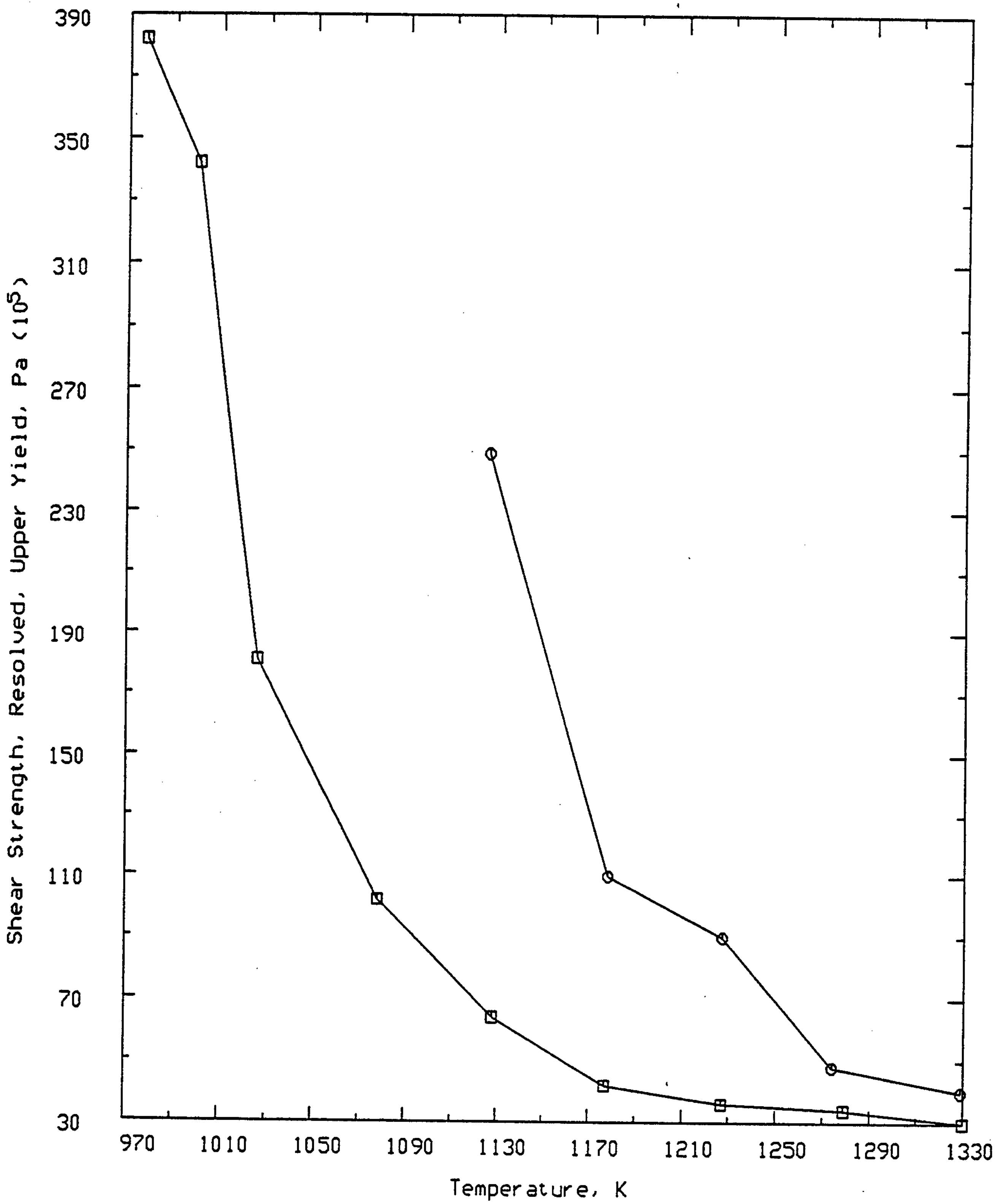

Figure 193 Shear Strength, Resolved, Upper Yield of Silicon, n-type

MATERIAL: Silicon, n-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield	DATA SET 194

****

Vendor/Producer/Fabricator

Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation

Crystal Growing Method :

Float-zone technique

Crystal grown in a high purity argon gas atmosphere.

Descriptors-Textual :

Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	460.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Parameters-Textual :

Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.

Parameters-Codified :

Pressure : 1.3e-02 Pa

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X : Dislocation Density	m^{-2}
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Temperature	K
Z2 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2
1.700e+08	5.900e+07	1.073e+03	6.000e-04
1.700e+08	5.040e+07	1.073e+03	6.000e-04
1.400e+09	3.800e+07	1.073e+03	6.000e-04
3.900e+09	2.830e+07	1.073e+03	6.000e-04
8.900e+09	2.080e+07	1.073e+03	6.000e-04
1.800e+10	1.600e+07	1.073e+03	6.000e-04
4.300e+10	1.600e+07	1.073e+03	6.000e-04
1.600e+08	3.110e+07	1.073e+03	1.200e-04
1.600e+08	2.680e+07	1.073e+03	1.200e-04
1.600e+08	2.570e+07	1.073e+03	1.200e-04
1.600e+08	2.360e+07	1.073e+03	1.200e-04
2.400e+08	1.330e+07	1.073e+03	1.200e-04
6.200e+08	2.140e+07	1.073e+03	1.200e-04
1.900e+09	1.550e+07	1.073e+03	1.200e-04
8.900e+09	9.600e+06	1.073e+03	1.200e-04
9.900e+09	1.060e+07	1.073e+03	1.200e-04
1.600e+08	8.000e+06	1.173e+03	1.200e-04
1.800e+09	5.300e+06	1.173e+03	1.200e-04
3.500e+09	5.300e+06	1.173e+03	1.200e-04

Comments on Data

Dislocation density determined by etch-pit counting technique.
Yield strength decreases with increasing dislocation density.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A
50, 685-93, 1978.

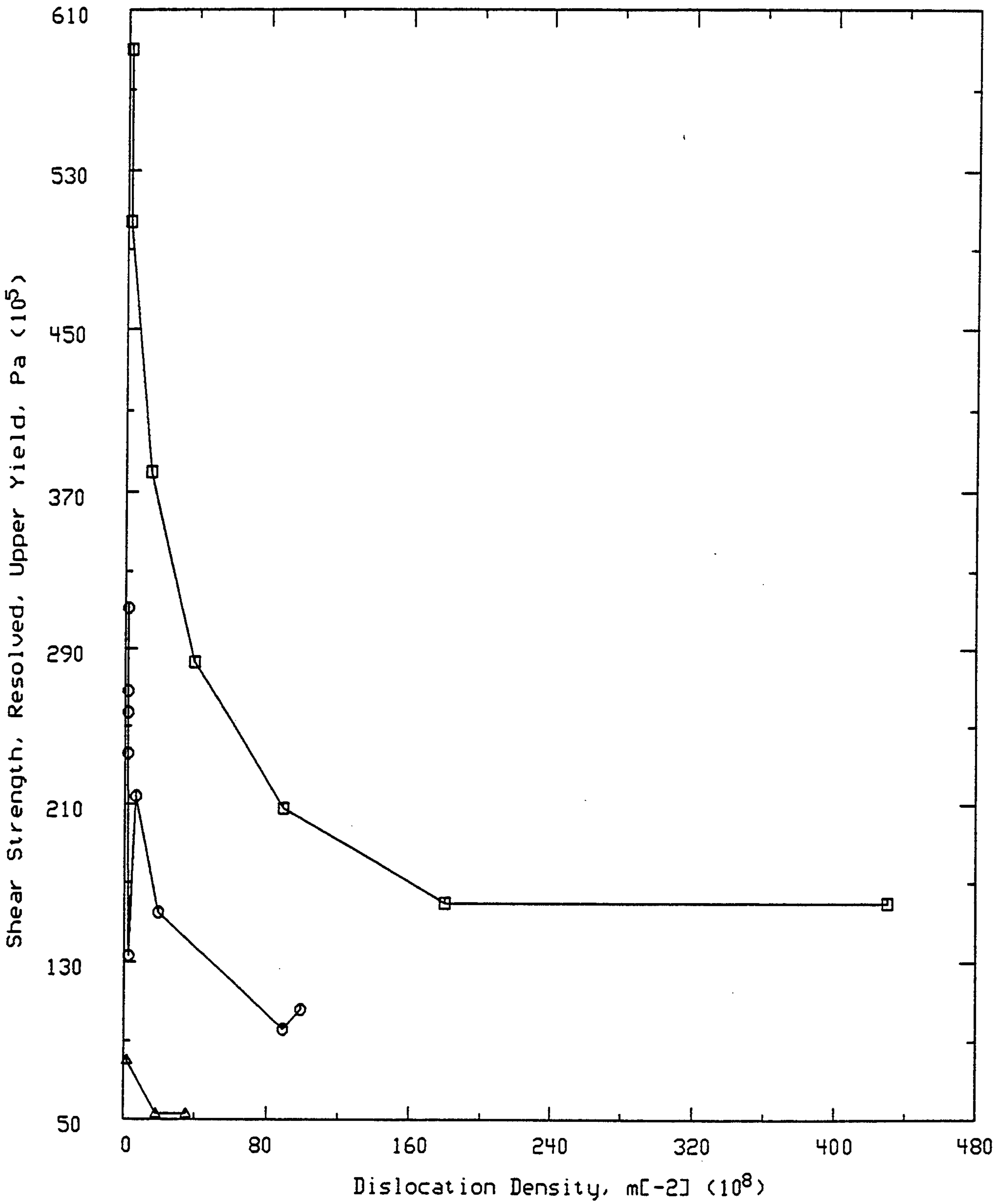

Figure 194 Shear Strength, Resolved, Upper Yield of Silicon, n-type

MATERIAL: Silicon, n-type

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 195

****

Vendor/Producer/Fabricator

Semiconductor Division of Tokyo Shibaura Electric Company Ltd.

Material Preparation

Crystal Growing Method :

Float-zone technique

Crystal grown in a high purity argon gas atmosphere.

Descriptors-Textual :

Dislocation density controlled by deformation at 1173 K and various strains(less than 10 pct shear strain). Specimens then subjected to thermal annealing for 24 hrs between 1273 and 1473 K.

Specimen Identification

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :		
Electrical Resistivity	460.	Ω cm
Temperature	298.	K
Other Properties-Numerical :		
Dislocation Density	2.0e04	cm^{-2}

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Parameters-Textual :

Tensile tests using an Instron-Type machine. All specimens showed homogeneous deformation along gauge length. No deformation by means of the propagation of luders bands occurred.

Parameters-Codified :

Pressure : 1.3e-02 Pa

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Descriptors-Numerical :

Pressure	1.e-04	torr

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
2.200e-05	1.610e+07	1.073e+03
2.300e-05	1.350e+07	1.073e+03
2.400e-05	1.540e+07	1.073e+03
5.600e-05	2.360e+07	1.073e+03
5.800e-05	2.070e+07	1.073e+03
6.100e-05	2.690e+07	1.073e+03
1.100e-04	2.560e+07	1.073e+03
1.200e-04	3.330e+07	1.073e+03
2.400e-04	3.940e+07	1.073e+03
5.200e-04	5.800e+07	1.073e+03
5.600e-04	6.900e+07	1.073e+03
2.400e-05	4.800e+06	1.173e+03
5.800e-05	8.700e+06	1.173e+03
1.200e-04	9.000e+06	1.173e+03
2.400e-04	1.390e+07	1.173e+03
5.900e-04	2.430e+07	1.173e+03
6.100e-04	2.130e+07	1.173e+03
6.000e-05	3.500e+06	1.273e+03
1.200e-04	3.800e+06	1.273e+03
2.400e-04	4.900e+06	1.273e+03
5.800e-04	7.500e+06	1.273e+03

Comments on Data

Yield strength increases with increasing stain rate.

Reference

DISLOCATION DYNAMICS IN THE PLASTIC DEFORMATION OF SILICON CRYSTALS. I. EXPERIMENTS.
Yonenaga, I. Sumino, K.
PHYS. STATUS SOLIDI A
50, 685-93, 1978.

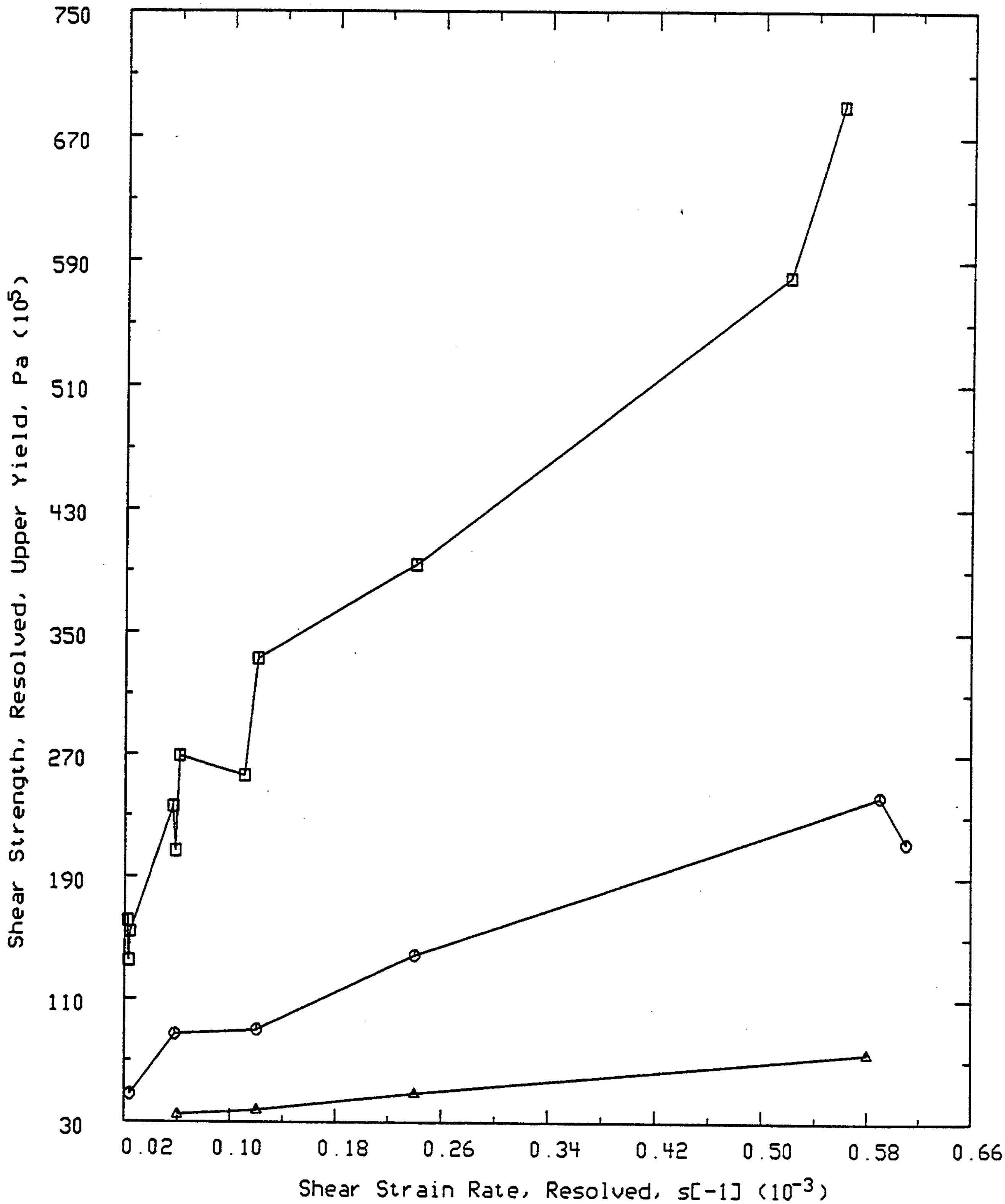

Figure 195 Shear Strength, Resolved, Upper Yield of Silicon, n-type

MATERIAL: Silicon, p-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield	DATA SET 196

****

Material Preparation

Crystal Growing Method :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	200-1200	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading
High-temperature apparatus mounted to Instron machine. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2). Resolved shear properties derived from measured stress-strain curves.

Measured/Evaluated Properties

X : Temperature	K
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1
1.367e+03	3.000e+06	2.390e-04
1.267e+03	6.100e+06	2.390e-04
1.215e+03	9.300e+06	2.390e-04
1.166e+03	1.350e+07	2.390e-04
1.115e+03	2.360e+07	2.390e-04

1.065e+03	3.770e+07	2.390e-04
1.367e+03	4.200e+06	4.770e-04
1.264e+03	8.700e+06	4.770e-04
1.218e+03	1.390e+07	4.770e-04
1.166e+03	2.010e+07	4.770e-04
1.113e+03	3.280e+07	4.770e-04
1.065e+03	5.210e+07	4.770e-04
1.014e+03	8.110e+07	4.770e-04

Comments on Data

Observed results for pure silicon were analyzed by means of dislocation theory. Dislocations move in viscous flow with an activation energy of 2.3 eV.

Reference

THE YIELD POINT OF SILICON AND SILICON-GERMANIUM SOLID SOLUTIONS.
Siethoff, H.
MATER. SCI. ENG.
4, 155-62, 1969.

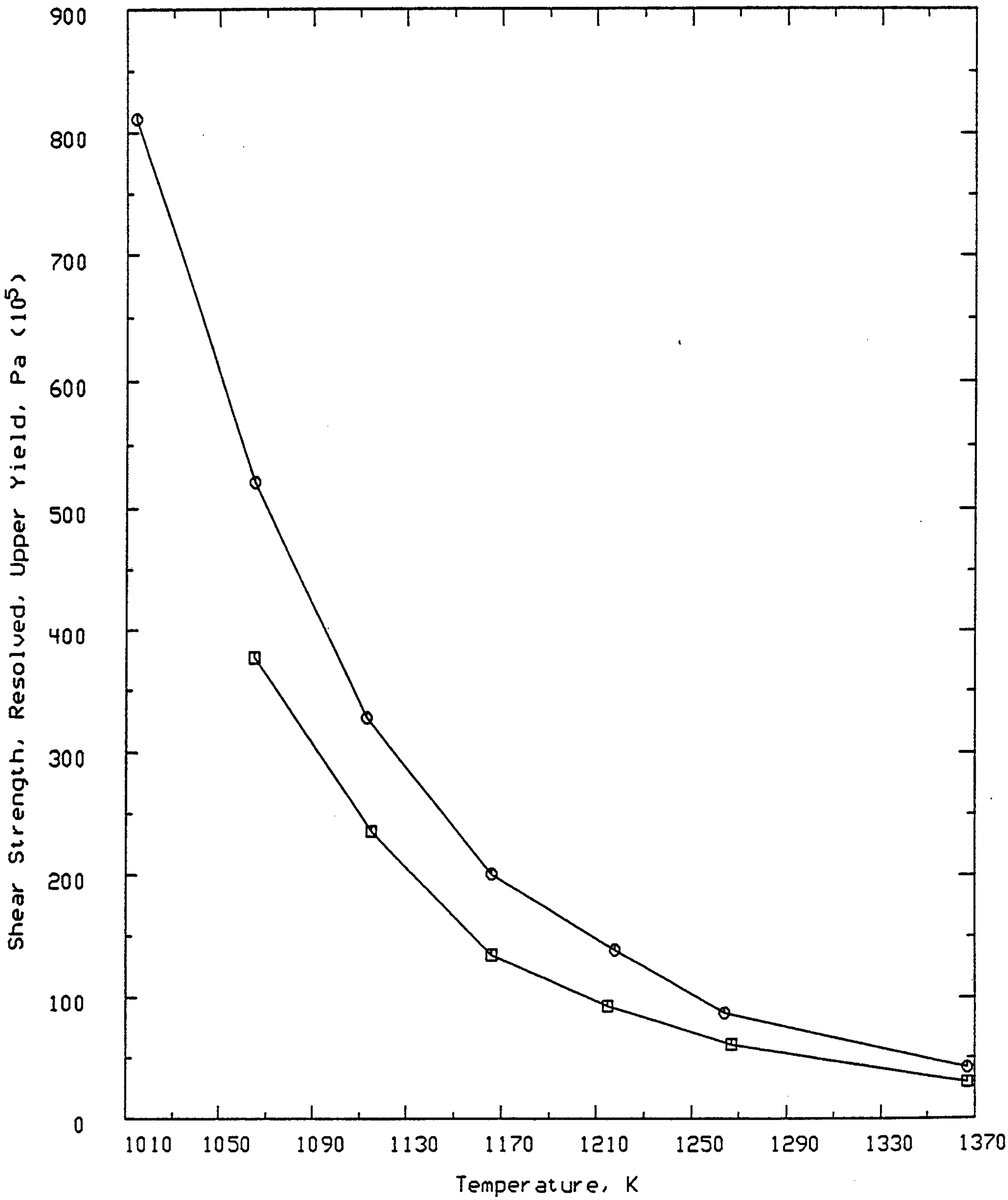

Figure 196 Shear Strength, Resolved, Upper Yield of Silicon, p-type

MATERIAL: Silicon, p-type

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 197

****

Material Preparation

Crystal Growing Method :

Czochralski silicon grown in the [111] orientation.

Descriptors-Textual :

Specimens machined by ultrasonic mill and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	3.4	cm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Primary slip system along (1-11){10-1}.

Dog-bone shaped tensile specimens

Additional Properties

Electrical Properties :

Electrical Resistivity	10. - 21.	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Measurements made on an MTS materials tester. Shear properties derived from measured tensile stress-strain.

Parameters-Codified :

Measurement Laboratory : Central Research Laboratories, Texas Instruments, Inc.,

Shear Strain Rate, Resolved : 5.5e-05 s[-1]

Temperature : 1073. K

Measured/Evaluated Properties

X	: Oxygen Concentration	ppm (atomic)
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K
Z2	: Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2	Remarks:
2.110e+01	3.050e+07	1.073e+03	5.500e-05	as-received
2.110e+01	4.760e+07	1.073e+03	5.500e-05	

2.380e+01	3.410e+07	1.073e+03	5.500e-05	
2.380e+01	3.620e+07	1.073e+03	5.500e-05	
2.380e+01	3.830e+07	1.073e+03	5.500e-05	
2.380e+01	3.900e+07	1.073e+03	5.500e-05	
2.380e+01	4.510e+07	1.073e+03	5.500e-05	
2.380e+01	4.540e+07	1.073e+03	5.500e-05	
2.380e+01	4.610e+07	1.073e+03	5.500e-05	
2.380e+01	5.330e+07	1.073e+03	5.500e-05	
2.380e+01	5.400e+07	1.073e+03	5.500e-05	
2.380e+01	5.470e+07	1.073e+03	5.500e-05	
2.380e+01	5.500e+07	1.073e+03	5.500e-05	
2.560e+01	3.580e+07	1.073e+03	5.500e-05	
2.560e+01	6.110e+07	1.073e+03	5.500e-05	
2.850e+01	4.220e+07	1.073e+03	5.500e-05	
2.850e+01	4.470e+07	1.073e+03	5.500e-05	
2.850e+01	4.690e+07	1.073e+03	5.500e-05	
2.850e+01	5.790e+07	1.073e+03	5.500e-05	
2.940e+01	4.610e+07	1.073e+03	5.500e-05	
2.940e+01	4.010e+07	1.073e+03	5.500e-05	
2.940e+01	4.540e+07	1.073e+03	5.500e-05	
2.940e+01	4.760e+07	1.073e+03	5.500e-05	
2.940e+01	4.970e+07	1.073e+03	5.500e-05	
3.460e+01	5.220e+07	1.073e+03	5.500e-05	
3.460e+01	5.650e+07	1.073e+03	5.500e-05	
2.110e+01	3.900e+07	1.073e+03	5.500e-05	as-received,average
2.270e+01	5.110e+07	1.073e+03	5.500e-05	
2.380e+01	4.260e+07	1.073e+03	5.500e-05	
2.560e+01	4.860e+07	1.073e+03	5.500e-05	
2.850e+01	4.900e+07	1.073e+03	5.500e-05	
2.940e+01	4.540e+07	1.073e+03	5.500e-05	
3.460e+01	5.430e+07	1.073e+03	5.500e-05	

Comments on Data

Data read from Figure 5.
Yield properties dominated by surface imperfections; dislocations can be nucleated which might account for the spread in data.
No significant effect of dissolved oxygen is seen on yield strength of as-grown crystals.

Reference

YIELD STRESS OF CZOCHRALSKI SILICON-THE EFFECT OF IMPURITIES AND OXYGEN PRECIPITATE MORPHOLOGY.

Lawrence, J. D.   Tsai, H. L.

OXYGEN, CARBON, HYDROGEN AND NITROGEN IN CRYSTALLINE SILICON
59, 389-94, 1986.
(Edited by J. C. Mikkelsen, Jr., S. J. Pearton,
J. W. Corbett and S. J. Pennycook; Mater. Res. Soc:
Pittsburgh, Pennsylvania)

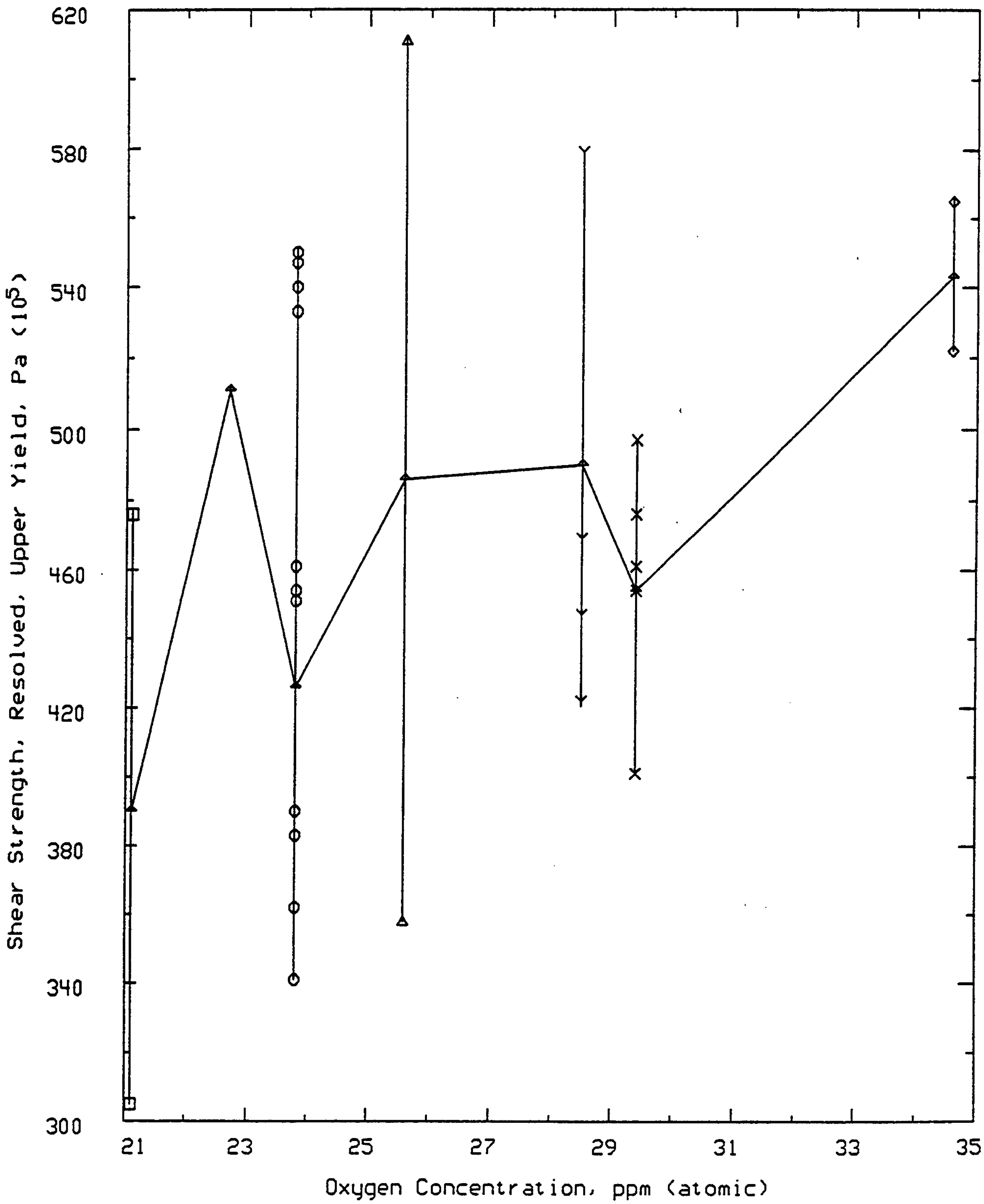

Figure 197 Shear Strength, Resolved, Upper Yield of Silicon, p-type

MATERIAL: Silicon, p-type

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 198

****

Material Preparation

Crystal Growing Method :

Czochralski silicon grown in the [111] orientation.

Descriptors-Textual :

Specimens machined by ultrasonic mill and chemically polished.

Specimens annealed to cause oxygen precipitation.

Specimen Identification

Dimensions (Geometry) :

Length	3.4	cm

Orientation With Respect To Material : [123] Direction

Additional Identifiers :

Primary slip system along (1-11){10-1}.

Dog-bone shaped tensile specimens

Additional Properties

Electrical Properties :

Electrical Resistivity	10. - 21.	Ω cm
Temperature	298.	K

Other Properties-Textual :

Specimens with an initial dissolved oxygen concentration of 29.5 +/- 0.5 ppma

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Measurements made on an MTS materials tester. Shear properties derived from measured tensile stress-strain.

Parameters-Codified :

Measurement Laboratory : Central Research Laboratories, Texas Instruments, Inc.,

Shear Strain Rate, Resolved : 5.5e-05 s[-1]

Temperature : 1073. K

Measured/Evaluated Properties

X	: Oxygen Concentration	ppm (atomic)
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K
Z2	: Shear Strain Rate, Resolved	s^{-1}
Z3	: Carbon Concentration	ppm (atomic)

Data Points :

X	Y	Z1	Z2	Z3	Remarks:
1.200e-01	4.990e+07	1.073e+03	5.500e-05	5.000e-01	**
1.300e-01	4.630e+07	1.073e+03	5.500e-05	5.000e-01	
1.400e-01	4.060e+07	1.073e+03	5.500e-05	5.000e-01	
1.700e+00	4.640e+07	1.073e+03	5.500e-05	5.000e-01	
1.800e+00	3.560e+07	1.073e+03	5.500e-05	5.000e-01	
1.800e+00	3.490e+07	1.073e+03	5.500e-05	5.000e-01	
4.900e+00	3.100e+07	1.073e+03	5.500e-05	5.000e-01	
4.900e+00	2.780e+07	1.073e+03	5.500e-05	5.000e-01	
5.100e+00	3.600e+07	1.073e+03	5.500e-05	5.000e-01	
7.300e+00	2.640e+07	1.073e+03	5.500e-05	5.000e-01	
1.470e+01	1.320e+07	1.073e+03	5.500e-05	5.000e-01	
1.480e+01	2.000e+07	1.073e+03	5.500e-05	5.000e-01	
1.480e+01	1.900e+07	1.073e+03	5.500e-05	5.000e-01	
1.480e+01	1.680e+07	1.073e+03	5.500e-05	5.000e-01	
1.900e-01	5.780e+07	1.073e+03	5.500e-05	1.500e+00	***
2.300e-01	4.740e+07	1.073e+03	5.500e-05	1.500e+00	
3.200e-01	4.530e+07	1.073e+03	5.500e-05	1.500e+00	
3.200e-01	4.460e+07	1.073e+03	5.500e-05	1.500e+00	
3.200e-01	4.260e+07	1.073e+03	5.500e-05	1.500e+00	
3.800e+00	4.350e+07	1.073e+03	5.500e-05	1.500e+00	
3.800e+00	3.390e+07	1.073e+03	5.500e-05	1.500e+00	
3.800e+00	3.280e+07	1.073e+03	5.500e-05	1.500e+00	
3.800e+00	3.140e+07	1.073e+03	5.500e-05	1.500e+00	
8.800e+00	2.030e+07	1.073e+03	5.500e-05	1.500e+00	
8.900e+00	2.250e+07	1.073e+03	5.500e-05	1.500e+00	
8.900e+00	2.210e+07	1.073e+03	5.500e-05	1.500e+00	
9.000e+00	1.960e+07	1.073e+03	5.500e-05	1.500e+00	
1.280e+01	1.640e+07	1.073e+03	5.500e-05	1.500e+00	
2.160e+01	1.120e+07	1.073e+03	5.500e-05	1.500e+00	
2.180e+01	1.290e+07	1.073e+03	5.500e-05	1.500e+00	

Comments on Data

Data read from Figure 6.
**Value given as <0.5, annealed for 36 hrs. at 1323 K.
***Annealed for 16 hrs. at 1323 K.
Specimens contained an initial dissolved oxygen concentrations of 29.5 +/- 0.5 ppma.
Results show that carbon plays an indirect role in reducing the yield strength.

Reference

YIELD STRESS OF CZOCHRALSKI SILICON-THE EFFECT OF

IMPURITIES AND OXYGEN PRECIPITATE MORPHOLOGY.
Lawrence, J. D. Tsai, H. L.
OXYGEN, CARBON, HYDROGEN AND NITROGEN IN CRYSTALLINE SILICON
59, 389-94, 1986.
(Edited by J. C. Mikkelsen, Jr., S. J. Pearton,
J. W. Corbett and S. J. Pennycook; Mater. Res. Soc:
Pittsburgh, Pennsylvania)

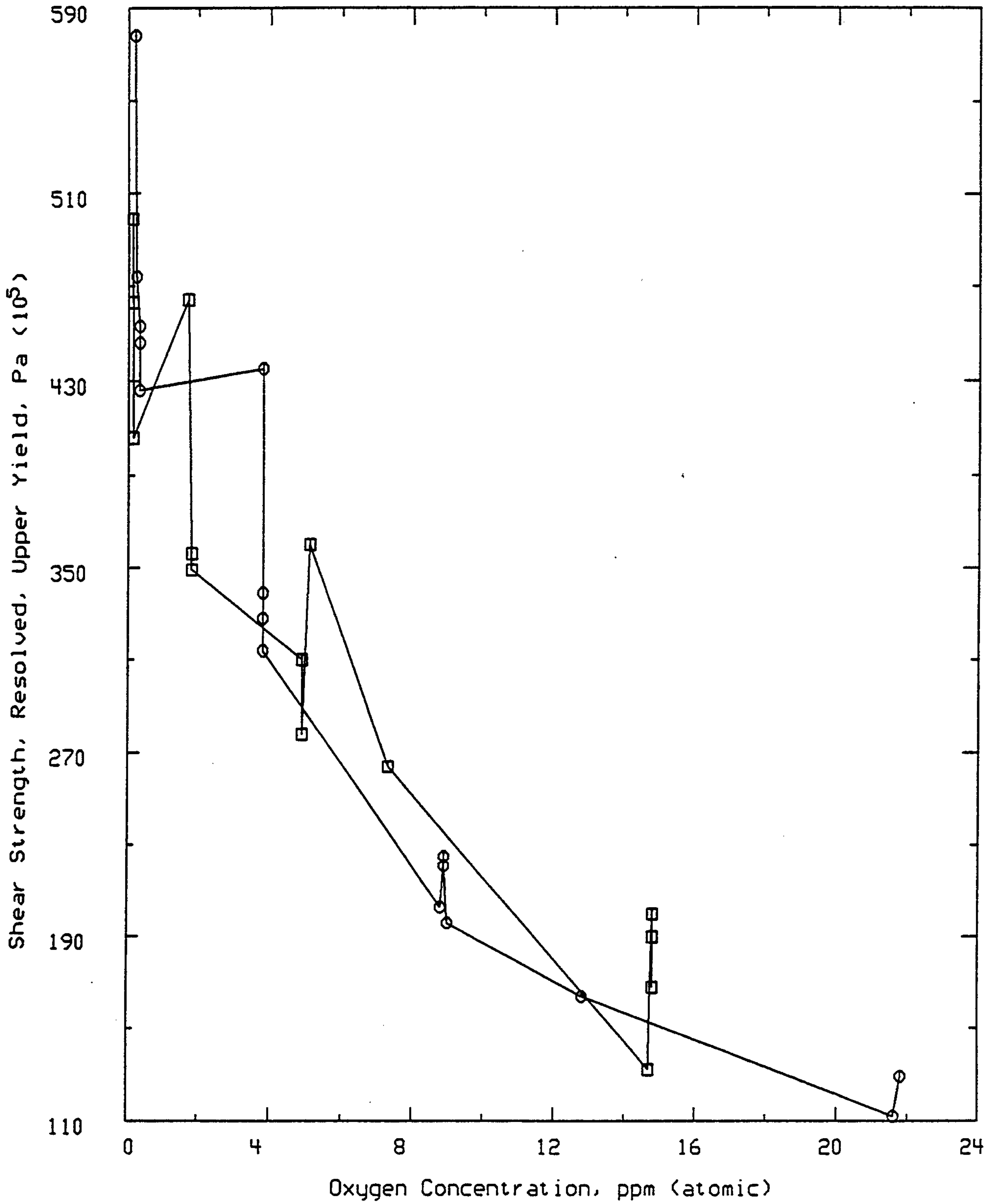

Figure 198 Shear Strength, Resolved, Upper Yield of Silicon, p-type

MATERIAL: Silicon, p-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield	DATA SET 199

****

Material Preparation

Crystal Growing Method :

Float-zone, p-type, dislocation free

Additional Preparation/Conditioning

Surface Treatment :

The surfaces were lapped with diamond paste and chemically polished

Specimen Identification

Dimensions (Geometry) :

Length	15.	mm
Width	3.4	mm
Thickness	3.4	mm

Orientation With Respect To Material : [123] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	200-1200	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Compressive Loading
High-temperature apparatus mounted to Instron machine. Tests carried under an atmosphere of forming gas (92 pct N2, 8 pct H2). Resolved shear properties derived from measured stress-strain curves.

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
2.500e-04	2.530e+07	1.273e+03
4.800e-04	2.940e+07	1.273e+03
1.200e-03	3.950e+07	1.273e+03
2.400e-03	4.260e+07	1.273e+03
4.900e-03	5.320e+07	1.273e+03

1.200e-02	6.520e+07	1.273e+03
1.200e-04	3.220e+07	1.173e+03
2.500e-04	3.740e+07	1.173e+03
4.800e-04	4.500e+07	1.173e+03
1.200e-03	5.730e+07	1.173e+03
2.400e-03	6.650e+07	1.173e+03
4.900e-03	7.710e+07	1.173e+03
1.200e-02	9.640e+07	1.173e+03

Comments on Data

Observed results for pure silicon were analyzed by means of dislocation theory. Dislocations move in viscous flow with an activation energy of 2.3 eV.

Reference

THE YIELD POINT OF SILICON AND SILICON-GERMANIUM SOLID SOLUTIONS.
Siethoff, H.
MATER. SCI. ENG.
4, 155-62, 1969.

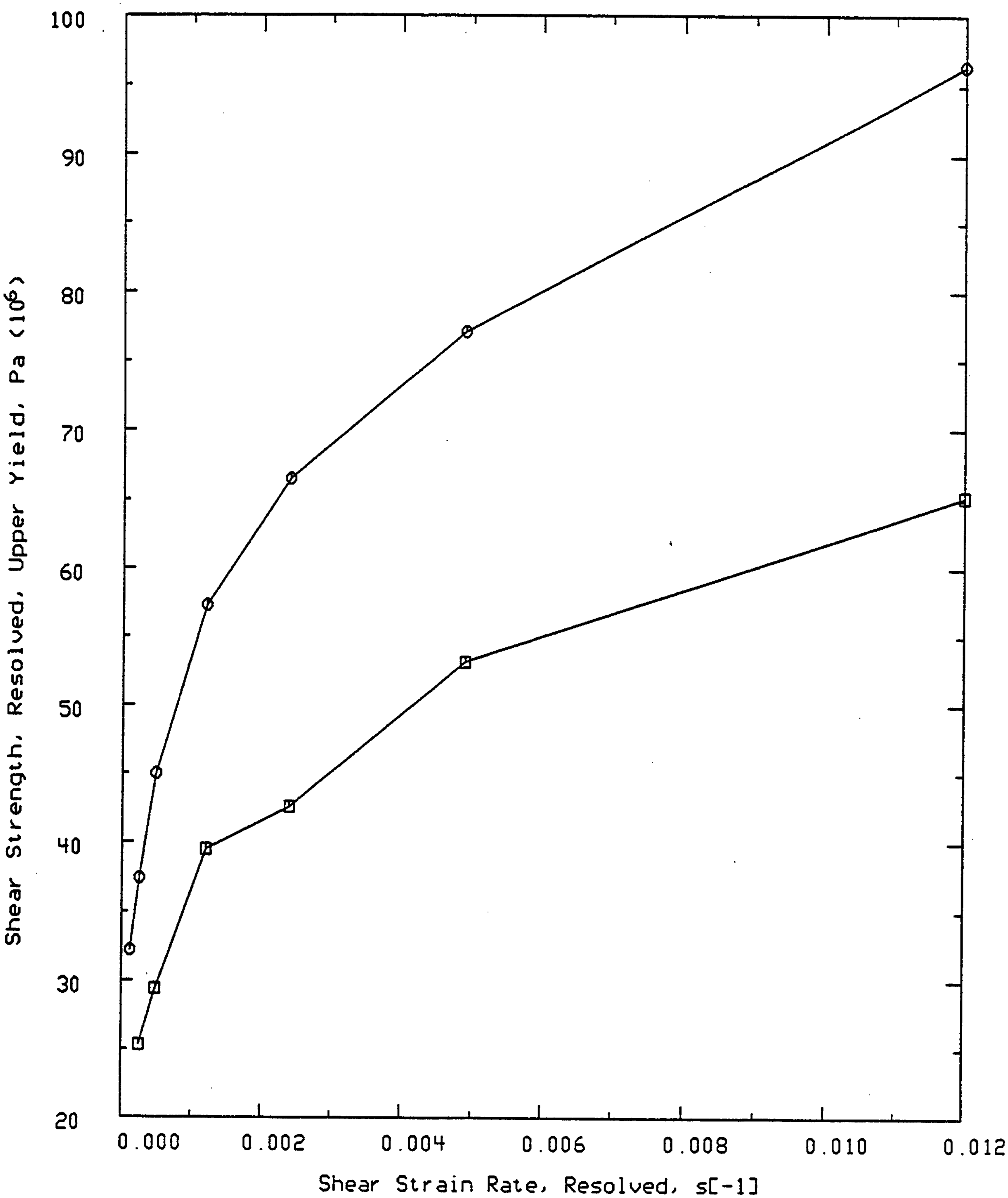

Figure 199 Shear Strength, Resolved, Upper Yield of Silicon, p-type

MATERIAL: Silicon

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 200

****

Composition

16-20	ppm (atomic)	Oxygen Concentration

Material Preparation

Crystal Growing Method :

Dendritic web silicon ribbons grown along a {211} crystal orientation with {111} surfaces.

Two thin single crystal sheets separated by odd number of twin planes.

Additional Preparation/Conditioning

Surface Treatment :

Laser cut along length of ribbon, along [211] direction.

After laser cut, mechanically polished with emery paper and diamond paste.

chemically polished using planar etch.

Specimen Identification

Dimensions (Geometry) :

Length	64.77	mm
Width	21.60	mm
Gauge-Section Thickness	25.40	mm
Gauge-Section Width	12.80	mm

Additional Identifiers :

Multiple slip orientation along (111)[101] and (111)[110] systems

Additional Properties

Other Properties-Numerical :

Dislocation Density	1.e+06	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Tensile axis of specimen is along the [211] direction, the ribbon growth direction.

Constant extension rates in a high temperature testing chamber mounted on a servohydraulic MTS machine.

Test performed in ultra high purity argon atmosphere.

Heating by infrared elliptical furnace.

Parameters-Textual :

All specimens strained to 5 percent elongation.
Parameters-Codified :
Strain Rate : 1.e-05 to 5.e-04 [s-1]
Elongation : 5 percent

Measured/Evaluated Properties

X : Temperature		K
Y : Shear Strength, Resolved, Upper Yield		Pa
Z1 : Shear Strain Rate, Resolved		s^{-1}

Data Points :

X	Y	Z1
1.273e+03	1.040e+07	5.000e-04
1.473e+03	5.490e+06	5.000e-04
1.573e+03	6.470e+06	5.000e-04
1.273e+03	5.790e+06	1.000e-04
1.373e+03	4.010e+06	1.000e-04
1.373e+03	3.730e+06	1.000e-04
1.373e+03	3.650e+06	1.000e-04
1.425e+03	2.940e+06	1.000e-04
1.473e+03	2.370e+06	1.000e-04
1.573e+03	3.490e+06	1.000e-04
1.173e+03	8.000e+06	1.000e-05
1.273e+03	4.450e+06	1.000e-05
1.373e+03	1.950e+06	1.000e-05
1.473e+03	1.450e+06	1.000e-05
1.573e+03	7.750e+06	1.000e-05

Comments on Data

Data was digitized from Figures 2,3.
Strengthening effect above 1473 k, most significant for slowest strain rate.
Yield strength was also referred to as strength at 2% offset.

Reference

HIGH TEMPERATURE (900-1300 DEGREES C) MECHANICAL BEHAVIOR OF DENDRITIC WEB GROWN SILICON RIBBONS: STRAIN RATE AND TEMPERATURE DEPENDENCE OF THE YIELD STRESS.
Mathews, V. K. Gross, T. S.
SCR. METALL.
21 (2), 117-22, 1987.

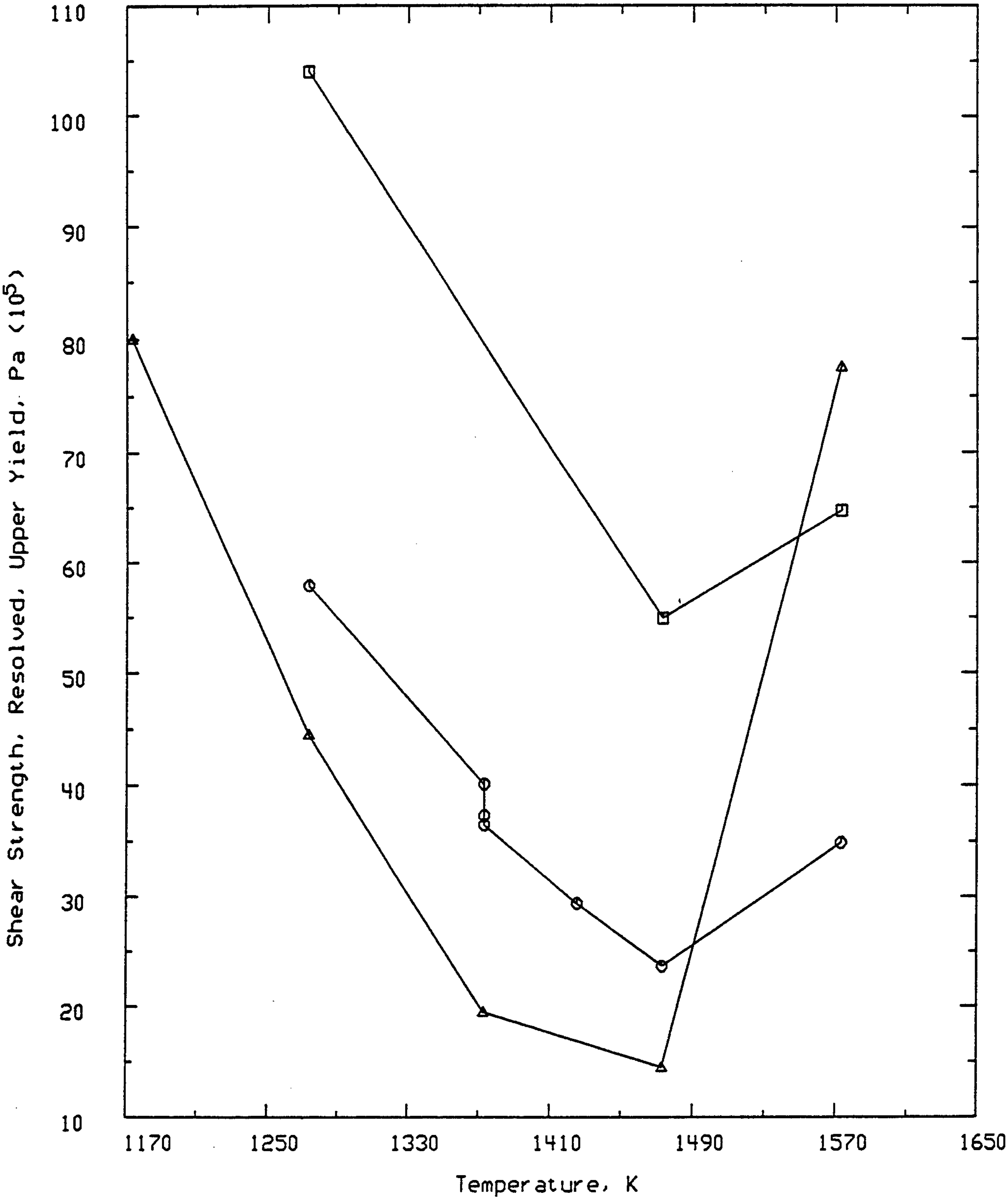

Figure 200 Shear Strength, Resolved, Upper Yield of Silicon

MATERIAL: Silicon

PROPERTY: Shear Strength, Resolved, Upper Yield

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 201

****

Composition

16-20	ppm (atomic)	Oxygen Concentration

Material Preparation

Crystal Growing Method :

Dendritic web silicon ribbons grown along a {211} crystal orientation with {111} surfaces.
Two thin single crystal sheets separated by odd number of twin planes.

Additional Preparation/Conditioning

Descriptors-Numerical :

Temperature	1573	K

Descriptors-Textual :

Specimen allowed to age at 1573 K for various durations before experiment.

Surface Treatment :

Laser cut along length of ribbon, along [211] direction.
After laser cut, mechanically polished with emery paper and diamond paste.
chemically polished using planar etch.

Specimen Identification

Dimensions (Geometry) :

Length	64.77	mm
Width	21.60	mm
Gauge-Section Thickness	25.40	mm
Gauge-Section Width	12.80	mm

Additional Identifiers :

Multiple slip orientation along (111)[101] and (111)[110] systems

Additional Properties

Other Properties-Numerical :

Dislocation Density	1.e+06	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading
Tensile axis of specimen is along the [211] direction, the ribbon growth direction.

Constant extension rates in a high temperature testing chamber mounted on a servohydraulic MTS machine.
Test performed in ultra high purity argon atmosphere.
Heating by infrared elliptical furnace.

Parameters-Textual :
All specimens strained to 5 percent elongation.

Parameters-Codified :
Strain Rate : 1.e-05 to 5.e-04 [s-1]
Elongation : 5 percent

Measured/Evaluated Properties

X : Aging Time	s
Y : Shear Strength, Resolved, Upper Yield	Pa
Z1 : Temperature	K
Z2 : Shear Strain Rate, Resolved	s^{-1}

Data Points :

X	Y	Z1	Z2
0.000e+00	3.340e+06	1.573e+03	1.000e-04
1.200e+03	4.490e+06	1.573e+03	1.000e-04
2.400e+03	6.760e+06	1.573e+03	1.000e-04

Comments on Data

Data was digitized from Figure 4.
Higher degree of segregation with increase in aging time.
Diffused oxygen atoms effectively lock dislocations resulting in higher strength with aging time.
Yield strength was also referred to as strength at 2% offset.

Reference

HIGH TEMPERATURE (900-1300 DEGREES C) MECHANICAL BEHAVIOR OF DENDRITIC WEB GROWN SILICON RIBBONS: STRAIN RATE AND TEMPERATURE DEPENDENCE OF THE YIELD STRESS.
Mathews, V. K. Gross, T. S.
SCR. METALL.
21 (2), 117-22, 1987.

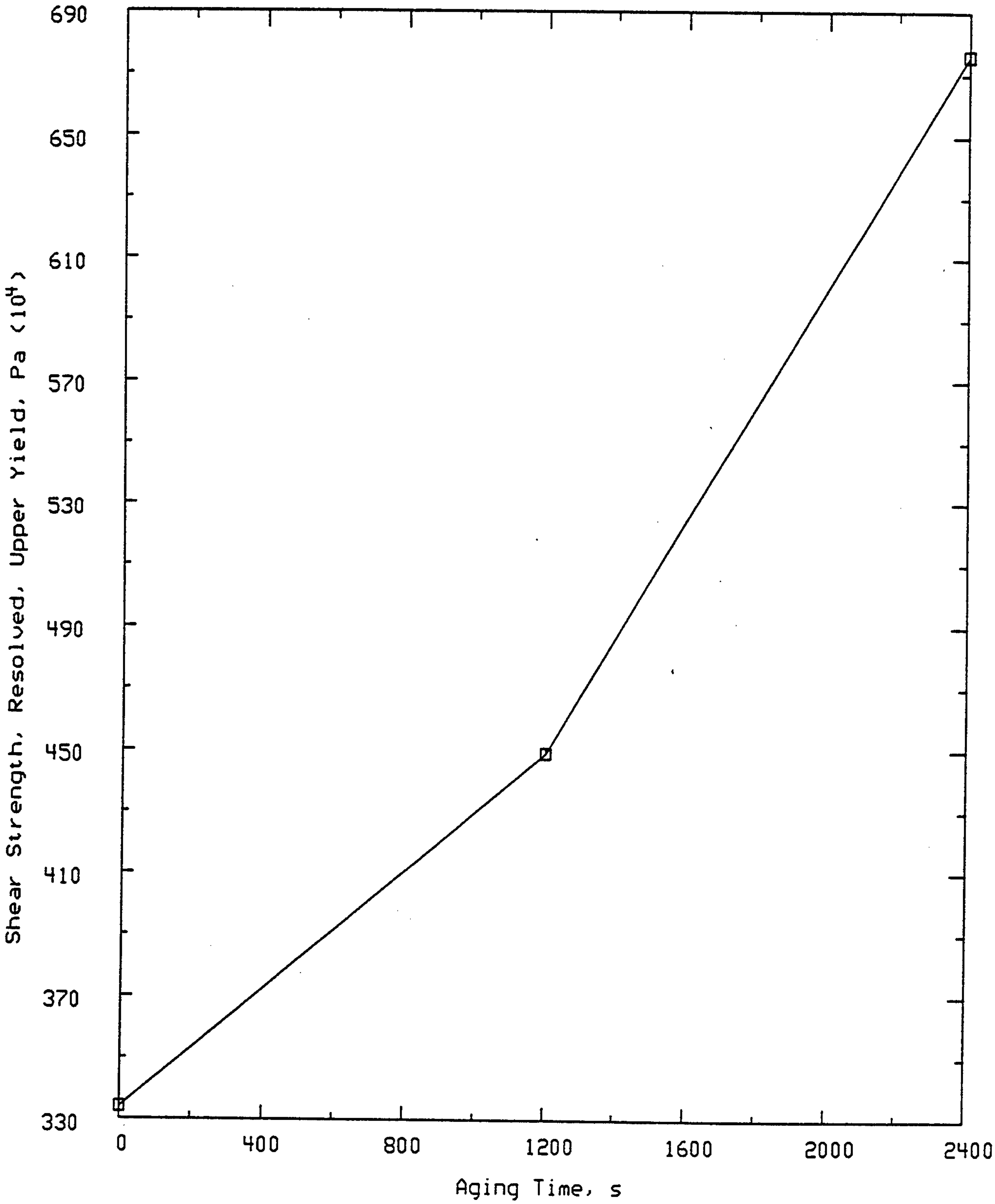

Figure 201 Shear Strength, Resolved, Upper Yield of Silicon

MATERIAL: Silicon | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Shear Strength, Resolved, Upper Yield | DATA SET 202

****

Composition

16-20	ppm (atomic)	Oxygen Concentration

Material Preparation

Crystal Growing Method :

Dendritic web silicon ribbons grown along a {211} crystal orientation with {111} surfaces.

Two thin single crystal sheets separated by odd number of twin planes.

Additional Preparation/Conditioning

Surface Treatment :

Laser cut along length of ribbon, along [211] direction.

After laser cut, mechanically polished with emery paper and diamond paste.

chemically polished using planar etch.

Specimen Identification

Dimensions (Geometry) :

Length	64.77	mm
Width	21.60	mm
Gauge-Section Thickness	25.40	mm
Gauge-Section Width	12.80	mm

Additional Identifiers :

Multiple slip orientation along (111)[101] and (111)[110] systems

Additional Properties

Other Properties-Numerical :

Dislocation Density	1.e+06	cm^{-2}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Shear Response Under Tensile Loading

Tensile axis of specimen is along the [211] direction, the ribbon growth direction.

Constant extension rates in a high temperature testing chamber mounted on a servohydraulic MTS machine.

Test performed in ultra high purity argon atmosphere.

Heating by infrared elliptical furnace.

Parameters-Textual :

All specimens strained to 5 percent elongation.
Parameters-Codified :
Strain Rate : 1.e-05 to 5.e-04 [s-1]
Elongation : 5 percent

Measured/Evaluated Properties

X	: Shear Strain Rate, Resolved	s^{-1}
Y	: Shear Strength, Resolved, Upper Yield	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
1.000e-05	4.500e+06	1.273e+03
1.000e-04	5.780e+06	1.273e+03
5.100e-04	1.027e+07	1.273e+03
1.000e-05	1.800e+06	1.373e+03
9.900e-05	3.590e+06	1.373e+03
1.000e-04	3.710e+06	1.373e+03
1.000e-04	4.010e+06	1.373e+03
1.000e-05	1.360e+06	1.473e+03
5.000e-05	2.570e+06	1.473e+03
1.000e-04	2.270e+06	1.473e+03
5.100e-04	5.890e+06	1.473e+03
9.900e-06	7.790e+06	1.573e+03
9.900e-05	3.420e+06	1.573e+03
5.100e-04	6.380e+06	1.573e+03

Comments on Data

Data was digitized from Figure 2.
Positive strain rate dependence for temperatures up to 1473 K.
At 1573 K there is a sharp change in the slope, and a negative strain rate dependence is observed.
Upper yield strength was also referred to as strength at 2 percent offset.

Reference

HIGH TEMPERATURE (900-1300 DEGREES C) MECHANICAL BEHAVIOR OF DENDRITIC WEB GROWN SILICON RIBBONS: STRAIN RATE AND TEMPERATURE DEPENDENCE OF THE YIELD STRESS.
Mathews, V. K.   Gross, T. S.

SCR. METALL.
21 (2), 117-22, 1987.

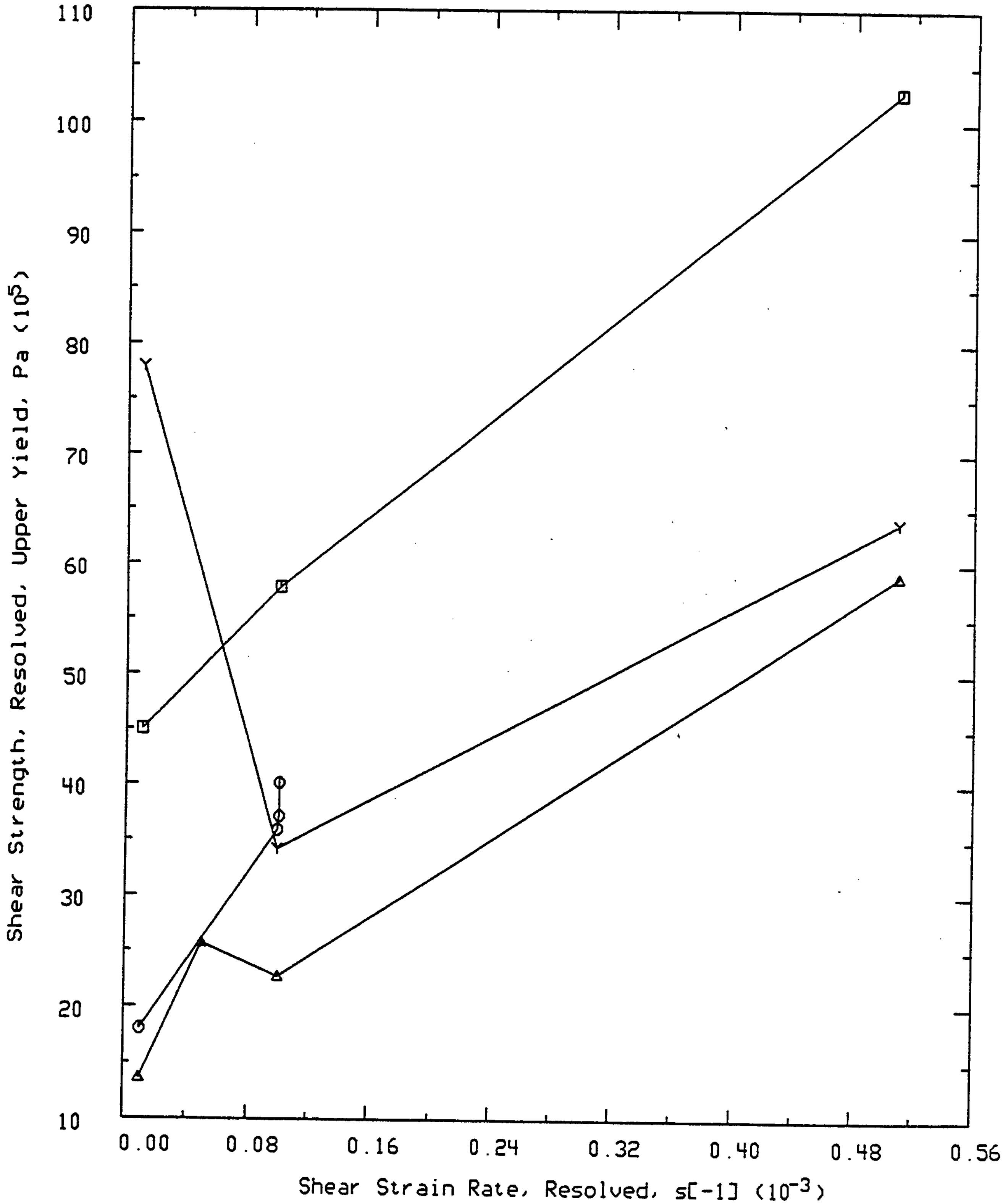

Figure 202 Shear Strength, Resolved, Upper Yield of Silicon

MATERIAL: Silicon: B doped	HTMIAC/CINDAS 1994 PURDUE UNIVERSITY
PROPERTY: Flexural Strength	DATA SET 203

****

Material Preparation

Crystal Growing Method :
Floating-Zone (FZ)

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :
Pre-cracked specimens were annealed in oxygen for at least 2 hours at 1100 C, 4 hours at 1000 C, or 10 hours at 900 C in order to heal the precursor cracks.

Material Microstructure

Dislocation-free 100 mm diameter (001) wafers
Interstitial oxygen (infra-red absorption): 1.0e+16 cm[-3] in FZ crystals.
Substitutional carbon content was below instrumental detection limit

Specimen Identification

Dimensions (Geometry) :

Length	32	mm
Width	4	mm
Thickness	0.5	mm

Orientation With Respect To Material : [100] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	17-23	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :
Four-Point Flexure on Pre-Cracked Specimens
Four-point bend test on pre-cracked and subsequently oxygen-annealed specimens.
Parameters-Codified :
Cross-Head Speed : 0.02mm min[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	4.000e+08	Data Scatter = +/- 50 MPa (approx.)

Comments on Data

Precursor cracks healed by annealing at from 900 C to 1100 C for an appropriate time.
The healing mechanism is the growth of a bonding layer of SiO(2), which proceeds as a reaction-rate-limited growth process.

Reference

CRACK HEALING AND FRACTURE STRENGTH OF SILICON CRYSTALS.
Yasutake, K. Iwata, M. Yoshii, K.
Umeno, M. Kawabe, H.
J. MATER. SCI.
21 (6), 2185-92, 1986.

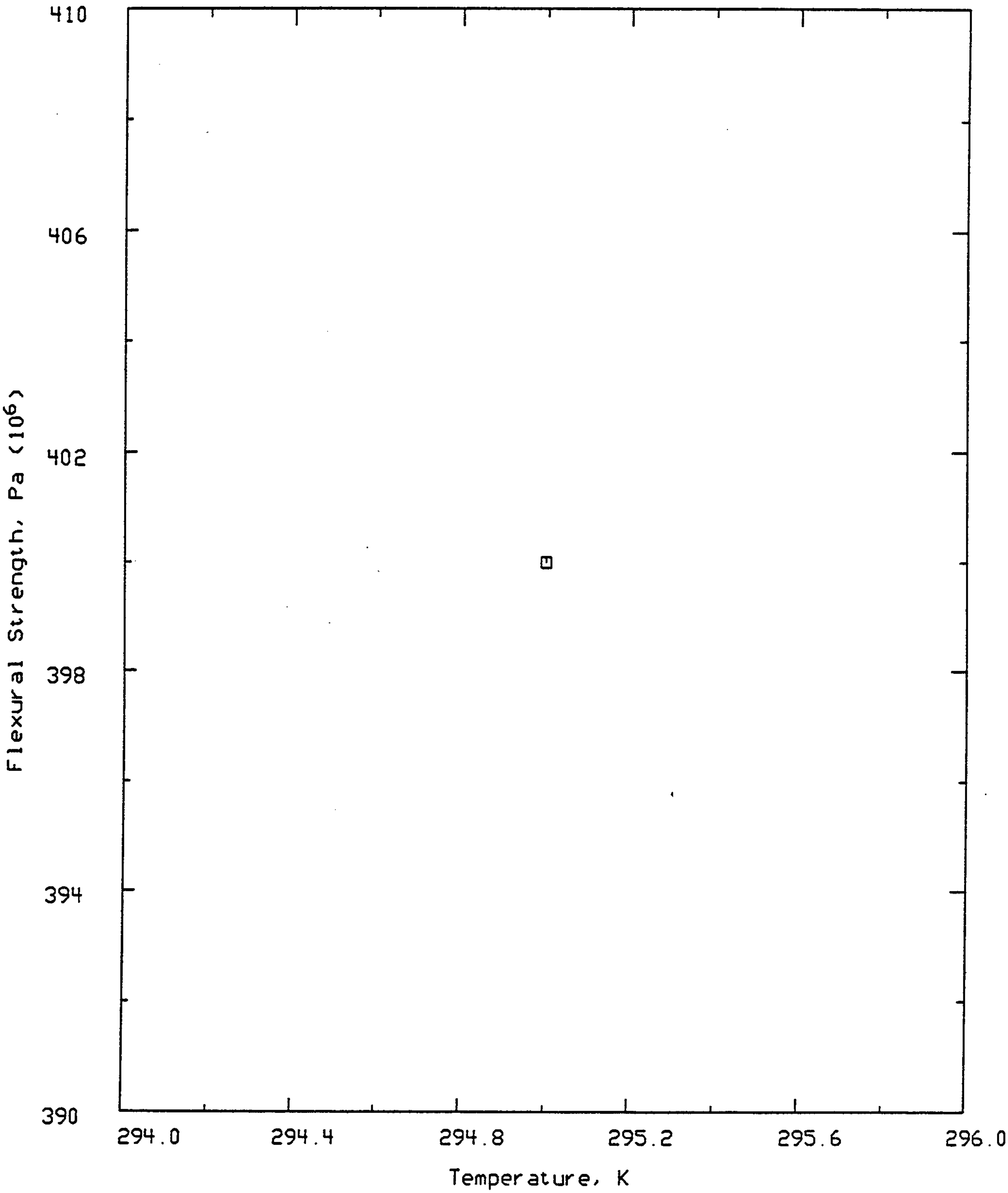

Figure 203 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 204

****

Composition

8e+17	cm^{-3}	Oxygen Concentration
8e+15	cm^{-3}	Boron Dopant Concentration

Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, p-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure Test
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Argon Environment

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	6.200e+09	Standard Deviation = 450 MPa

Comments on Data
Number of specimens was at least 15.

Reference
FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

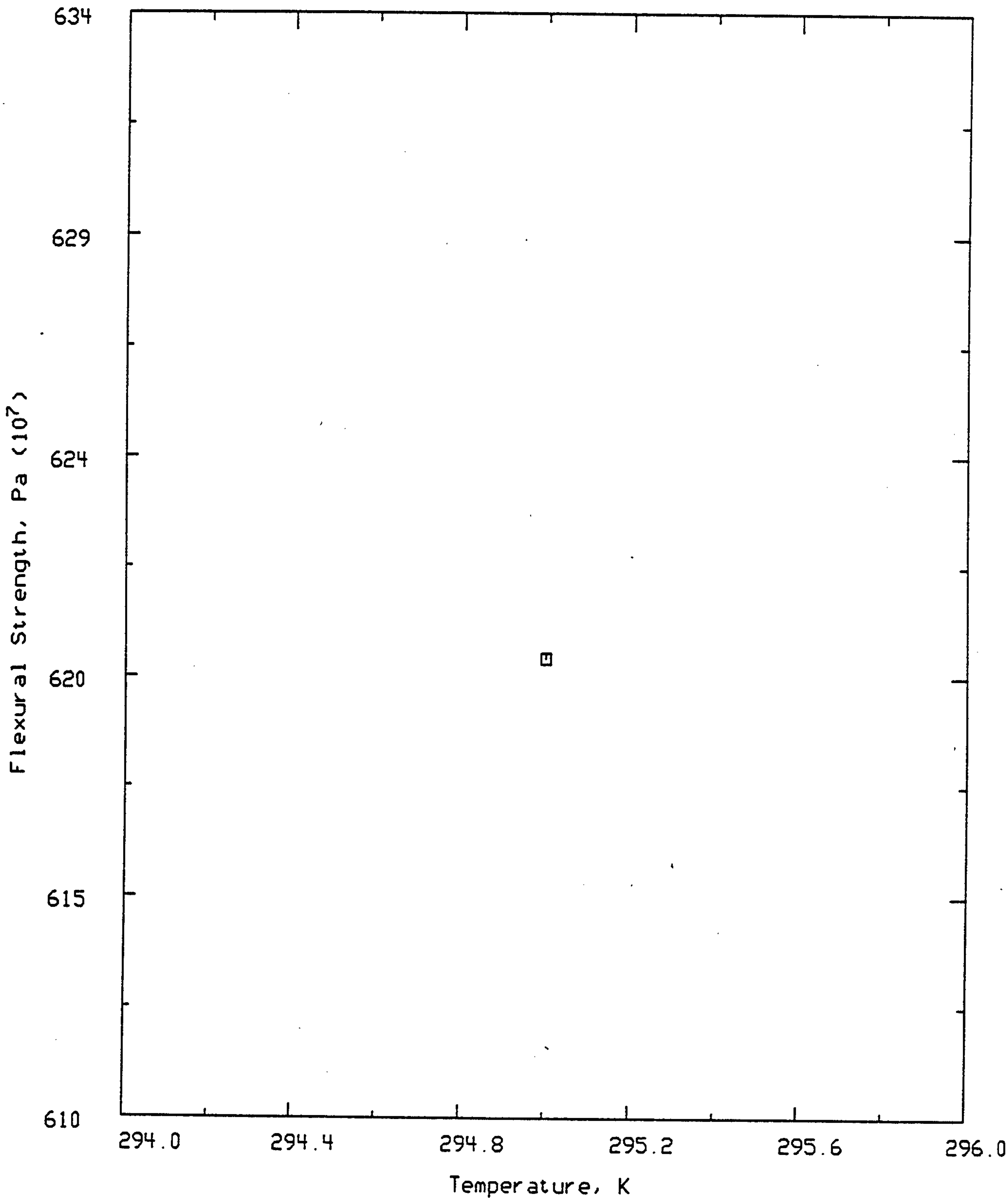

Figure 204 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 205

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Composition

3e+17	cm^{-3}	Oxygen Concentration
3e+16	cm^{-3}	Boron Dopant Concentration

Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :

Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).

This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, p-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Pneumatically Loaded Wafer Flexure Test

A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.

Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	6.120e+09	Standard Deviation = 450 MPa

Comments on Data

Number of specimens was at least 15.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

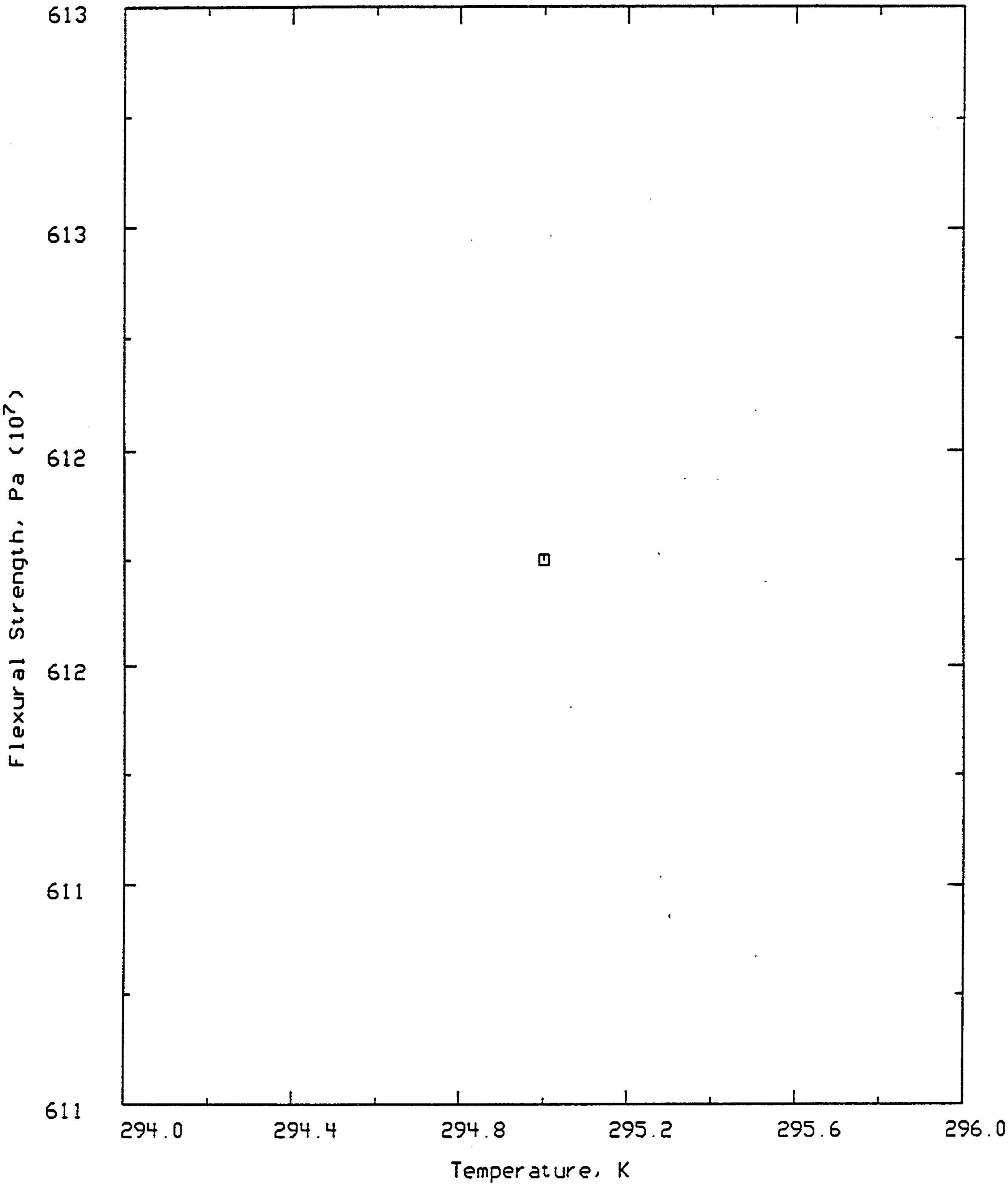

Figure 205 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 206

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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, p-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure Test
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.
Dopant concentrations were determined from standard electrical property measurements.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa
Z1	: Boron Dopant Concentration	m^{-3}

Data Points :

X	Y	Z1	Remarks:
2.950e+02	5.400e+07	5.000e+20	S.D. = 5.1 MPa, As-Cut Condition
2.950e+02	5.800e+07	2.500e+25	S.D. = 4.0 MPa
2.950e+02	7.300e+07	5.000e+20	S.D. = 7.1 MPa, As-Cut + Grounded
2.950e+02	7.100e+07	2.500e+25	S.D. = 6.0 MPa
2.950e+02	6.200e+09	5.000e+20	S.D. = 450 MPa, Chemically Etched
2.950e+02	6.000e+09	1.500e+21	S.D. = 510 MPa
2.950e+02	6.110e+09	3.000e+22	S.D. = 320 MPa
2.950e+02	5.790e+09	5.000e+22	S.D. = 400 MPa
2.950e+02	6.920e+09	5.000e+24	S.D. = 550 MPa
2.950e+02	8.340e+09	1.500e+25	S.D. = 630 MPa
2.950e+02	9.660e+09	2.500e+25	S.D. = 730 MPa

Comments on Data

Number of specimens was at least 15 per condition or dopant concentration.
High concentrations of boron dopant noticeably enhance the flexural strength.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

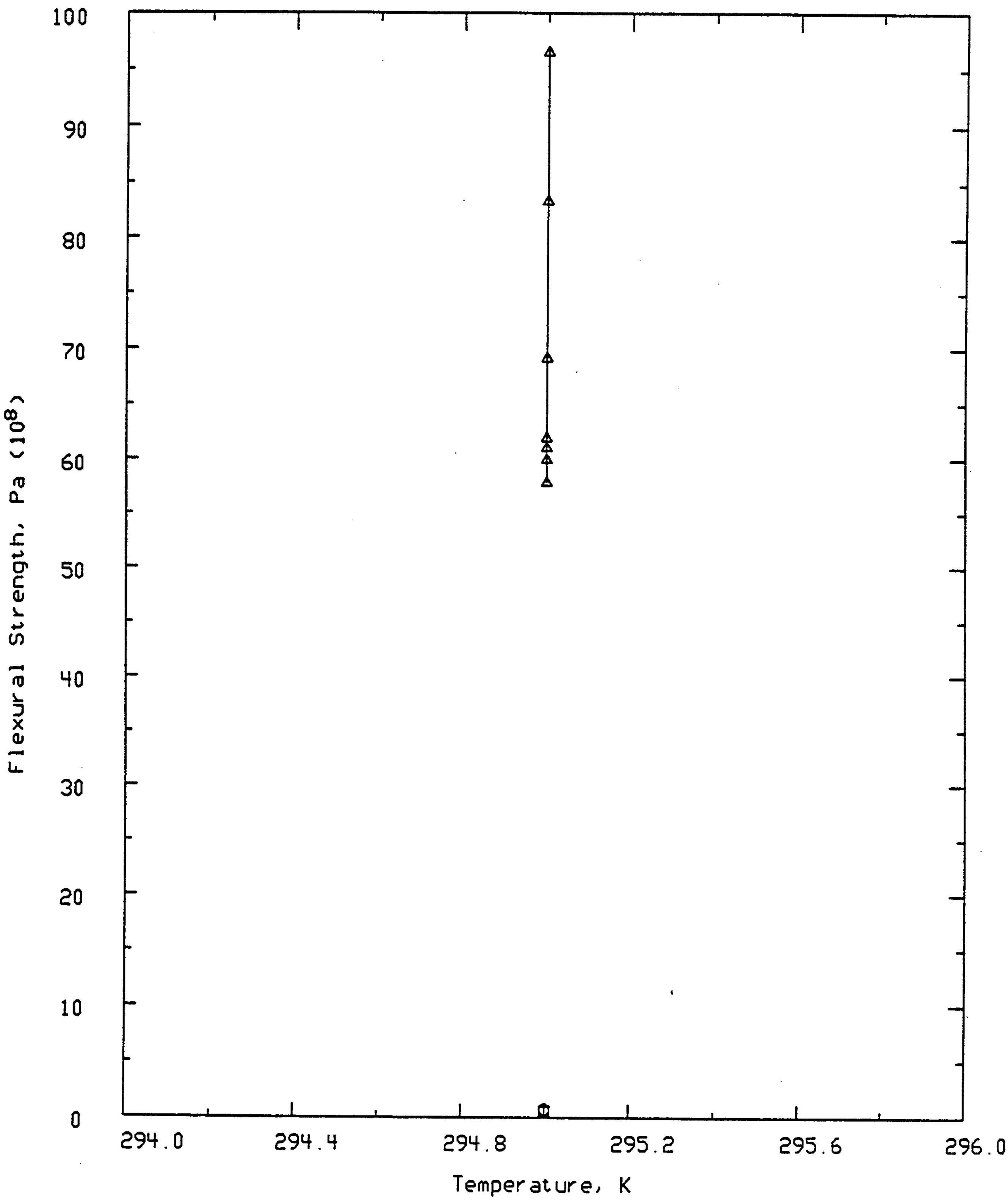

Figure 206 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 207

****

Material Preparation

Crystal Growing Method :
Float-Zoned

Additional Preparation/Conditioning

Surface Treatment :
As-received wafers had one mirror finish surface (tension surface) and one deep etched surface (compression surface). The deep etched surface was heavily etched with CP4 (HF:HNO(3):glacial acetic acid = 3:5:3).

Specimen Identification

Number/Name : Float-Zoned Si:B
Orientation With Respect To Material : (100) Plane

Additional Properties

Electrical Properties :

Electrical Resistivity	>600	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers.
Circular aluminum platform had 5 mm diameter hole with a beveled edge to provide concentric support.
Load was applied by a 5 mm ball attached to an Instron machine.
Crosshead speed was 100 micron/min.
Fracture load was converted to flexure strength (tensile surface stress at fracture) using elastic bending theory.

Measured/Evaluated Properties

X	: Thickness	m
Y	: Flexural Strength	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1	Remarks:
3.810e-04	3.100e+09	2.950e+02	S.D.=0.6 GPa, Un-etched
4.570e-04	3.300e+09	2.950e+02	S.D.=1.0 GPa, Un-etched
5.080e-04	3.000e+09	2.950e+02	S.D.=0.4 GPa, Un-etched

3.930e-04	3.400e+09	2.950e+02	S.D.=1.0 GPA, Etched from 457 mic.
4.050e-04	6.700e+09	2.950e+02	S.D.=1.4 GPa, Etched from 508 mic.

Comments on Data

Number of specimens was eight per thickness.
Surface morphology on compression side is considered to be the dominating factor in determining the fracture stress for float-zoned material.

Reference

FRACTURE OF SILICON WAFERS.
McLaughlin, J. C. Willoughby, A. F. W.
J. CRYST. GROWTH
85, 83-90, 1987.

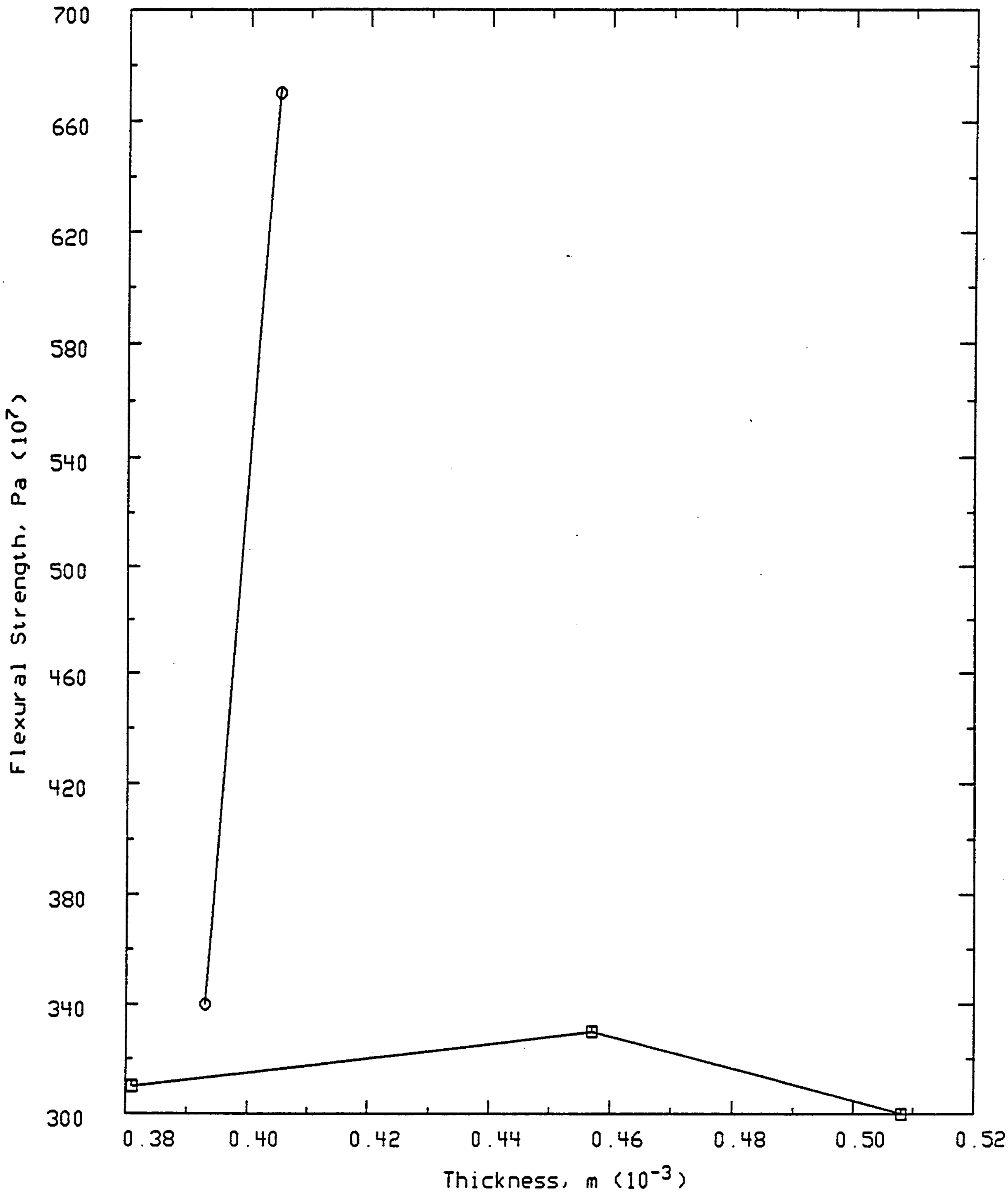

Figure 207 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

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PURDUE UNIVERSITY
DATA SET 208

****

Vendor/Producer/Fabricator

Mitsubishi Electric Corp.

Material Preparation

Crystal Growing Method :
Czochralski-grown crystals

Specimen Identification

Dimensions (Geometry) :

Length	32.	mm
Width	5.0	mm
Thickness	0.53	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	15-25	Ω cm
Temperature	298.	K

Other Properties-Numerical :

Oxygen Concentration	11.5e17	cm^{-3}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Four-Point Bend Test
Parameters-Textual :
Four-point loading device made of quartz and the distances between inner and outer knife-edges are 8 and 24 mm, respectively.
The device was attached to an Instron machine.
Parameters-Codified :
Strain Rate : 1.5e-06 s[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	2.033e+08	fracture

3.790e+02	2.294e+08	
4.780e+02	2.170e+08	
5.810e+02	2.600e+08	
6.770e+02	3.207e+08	
7.800e+02	5.984e+08	
8.000e+02	5.988e+08	
8.320e+02	4.596e+08	yield,fracture
8.360e+02	4.207e+08	
8.560e+02	3.424e+08	
8.760e+02	2.551e+08	
9.230e+02	1.793e+08	

Comments on Data

Data was digitized from figure 2
Fracture strength of the as-received CZ-wafers increases with T and becomes maximum at T approximately 793 K. In the T range 823-873 K, they fracture at almost the level of the yield strength, and at above 923 K, they become entirely ductile

Reference

MECHANICAL PROPERTIES OF HEAT-TREATED CZ-SILICON WAFERS FROM BRITTLE TO DUCTILE TEMPERATURE RANGE.
Yasutake, K. Murakami, J. Umeno, M.
Kawabe, H.
JPN. J. APPL. PHYS., PART 2
21 (5), 288-90, 1982.

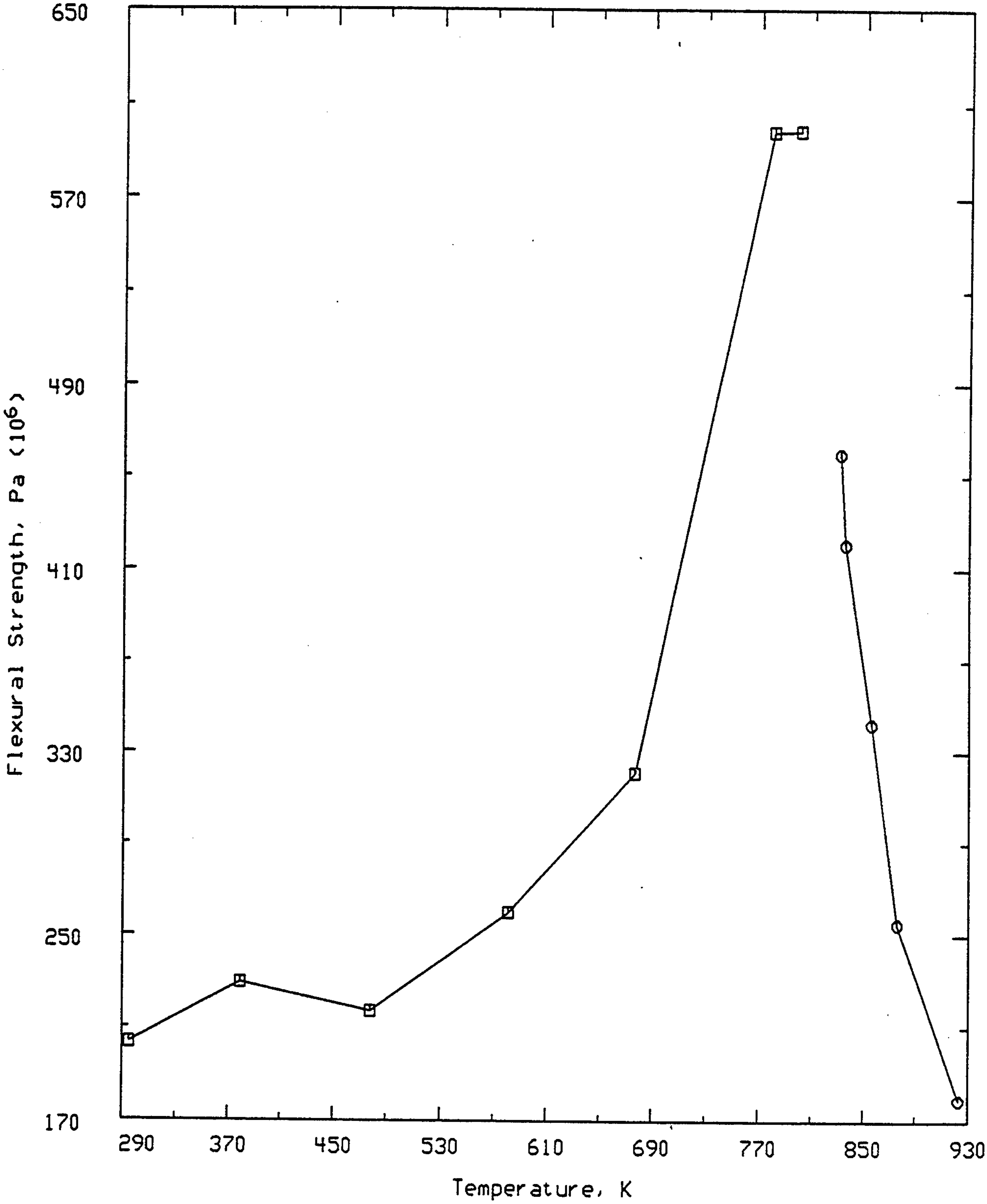

Figure 208 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 209

****

Vendor/Producer/Fabricator

Mitsubishi Electric Corp.

Material Preparation

Crystal Growing Method :
Floating-zone-grown crystals.

Specimen Identification

Dimensions (Geometry) :

Length	32.	mm
Width	5.0	mm
Thickness	0.53	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	15-25	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Four-Point Bend Test

Parameters-Textual :
Four-point loading device made of quartz and the distances between inner and outer knife-edges are 8 and 24 mm, respectively.
The device was attached to an Instron machine.

Parameters-Codified :
Strain Rate : 1.5e-06 s[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	1.806e+08	fracture
3.830e+02	1.922e+08	
4.780e+02	1.928e+08	
5.810e+02	2.380e+08	

6.810e+02	2.768e+08	
7.800e+02	5.317e+08	
8.000e+02	5.321e+08	
8.280e+02	5.021e+08	yield,fracture
8.560e+02	3.853e+08	
8.760e+02	2.706e+08	

Comments on Data

Data was digitized from figure 2
Fracture strength of as-received float-zone-grown wafers increases with T and becomes maximum at T approximately 793 K. At T = 823-873 K, wafers fracture at almost the level of the yield strength, and at above 923 K, they become entirely ductile.

Reference

MECHANICAL PROPERTIES OF HEAT-TREATED CZ-SILICON WAFERS FROM BRITTLE TO DUCTILE TEMPERATURE RANGE.
Yasutake, K. Murakami, J. Umeno, M.
Kawabe, H.
JPN. J. APPL. PHYS., PART 2
21 (5), 288-90, 1982.

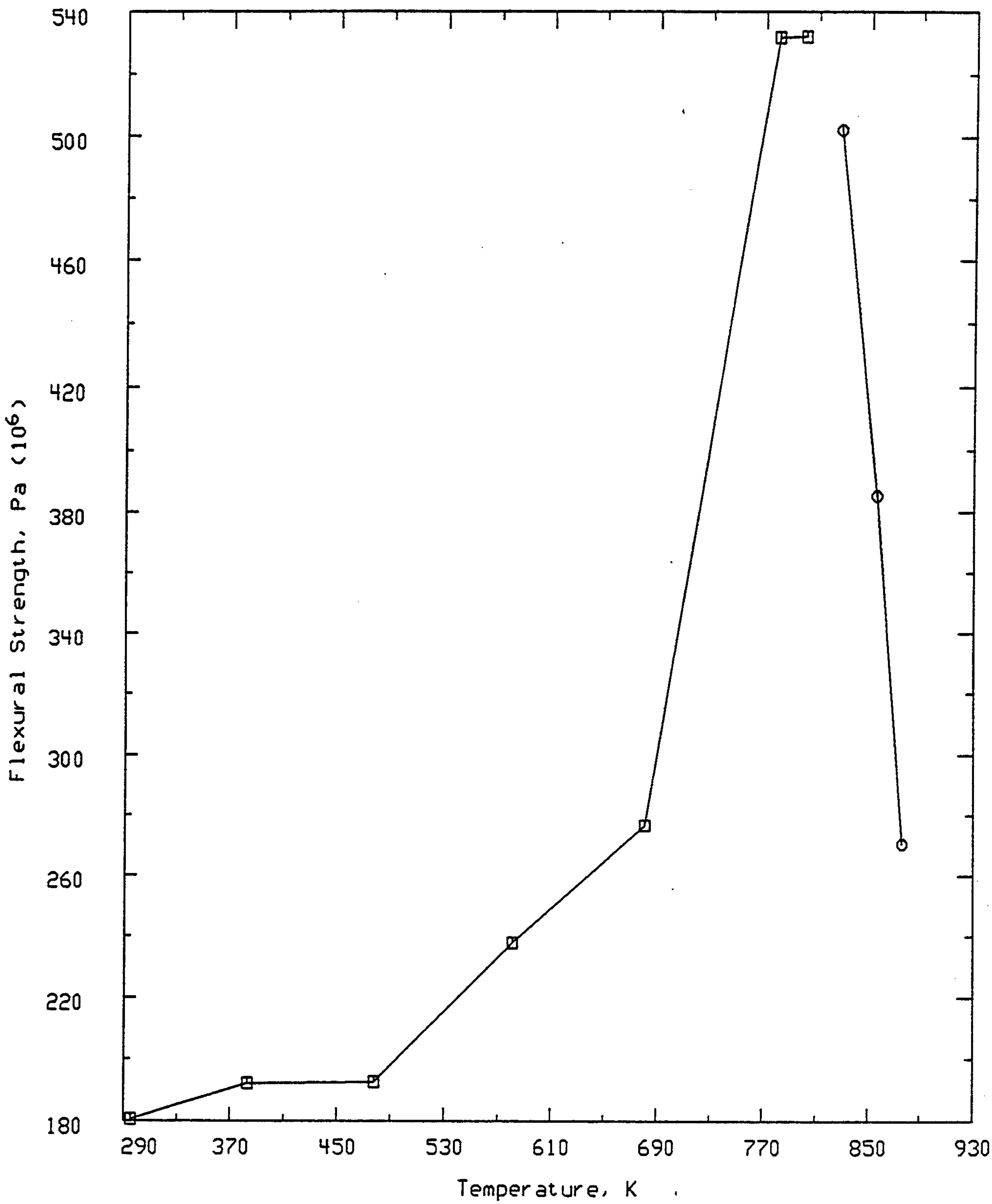

Figure 209 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: B doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 210

****

Vendor/Producer/Fabricator

Mitsubishi Electric Corp.

Material Preparation

Crystal Growing Method :
Czochralski-grown crystals
Descriptors-Textual :
Chemically ploished and then annealed at 1073 K for 100 hrs.

Specimen Identification

Dimensions (Geometry) :

Length	32.	mm
Width	5.0	mm
Thickness	0.53	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	15-25	Ω cm
Temperature	298.	K

Other Properties-Textual :
Etch pit density: approx. 8.0e09 cm[-3]
SiO(2) precipitate size: approx. 4200 Angstroms.

Measurement/Evaluation Method

Name/Description :
Four-Point Bend Test
Parameters-Textual :
Four-point loading device made of quartz and the distances between inner and outer knife-edges are 8 and 24 mm, respectively.
The device was attached to an Instron machine.
Parameters-Codified :
Strain Rate : 1.5e-06 s[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y
2.990e+02	1.306e+08
3.830e+02	1.473e+08
4.780e+02	1.615e+08
4.790e+02	1.037e+08
5.780e+02	1.072e+08
5.820e+02	1.528e+08
6.810e+02	1.211e+08
6.810e+02	1.778e+08
7.330e+02	2.392e+08
7.800e+02	4.199e+08

Comments on Data

Data was digitized from figure 2
Fracture strength at room temperature does not change with heat treatments if surface-denuded zones (DZ) present. Platelike SiO(2) precipitates of about 10.e10cm[-3] are observed by TEM and etch-pit method, but no punched-out dislocation loops exist. Annealed CZ wafers become ductile at T above 793 K.

Reference

MECHANICAL PROPERTIES OF HEAT-TREATED CZ-SILICON WAFERS FROM BRITTLE TO DUCTILE TEMPERATURE RANGE.
Yasutake, K. Murakami, J. Umeno, M.
Kawabe, H.
JPN. J. APPL. PHYS., PART 2
21 (5), 288-90, 1982.

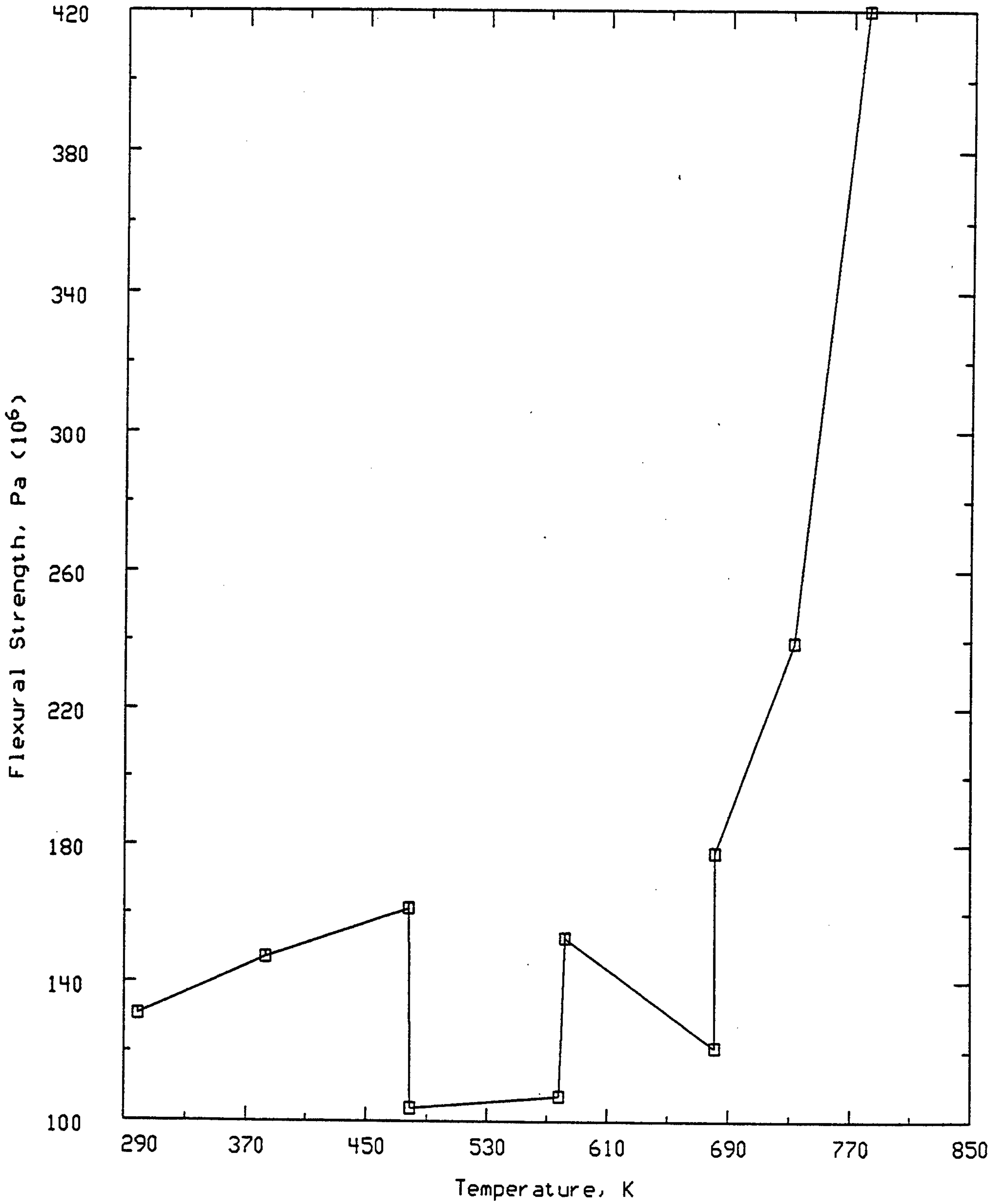

Figure 210 Flexural Strength of Silicon: B doped

MATERIAL: Silicon: Ga doped	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Flexural Strength	DATA SET 211

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Composition

3e+16	cm^{-3}	Gallium Dopant Concentration

Material Preparation

Crystal Growing Method :

Czochralski

Additional Preparation/Conditioning

Surface Treatment :

Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).

This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, p-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Pneumatically Loaded Wafer Flexure

Axisymmetric bending method employing pneumatic loading.

A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.

Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Argon Environment

Measured/Evaluated Properties

X : Temperature	K
Y : Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	6.150e+09	Standard Deviation = 430 MPa

Comments on Data

Number of specimens was at least 15.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

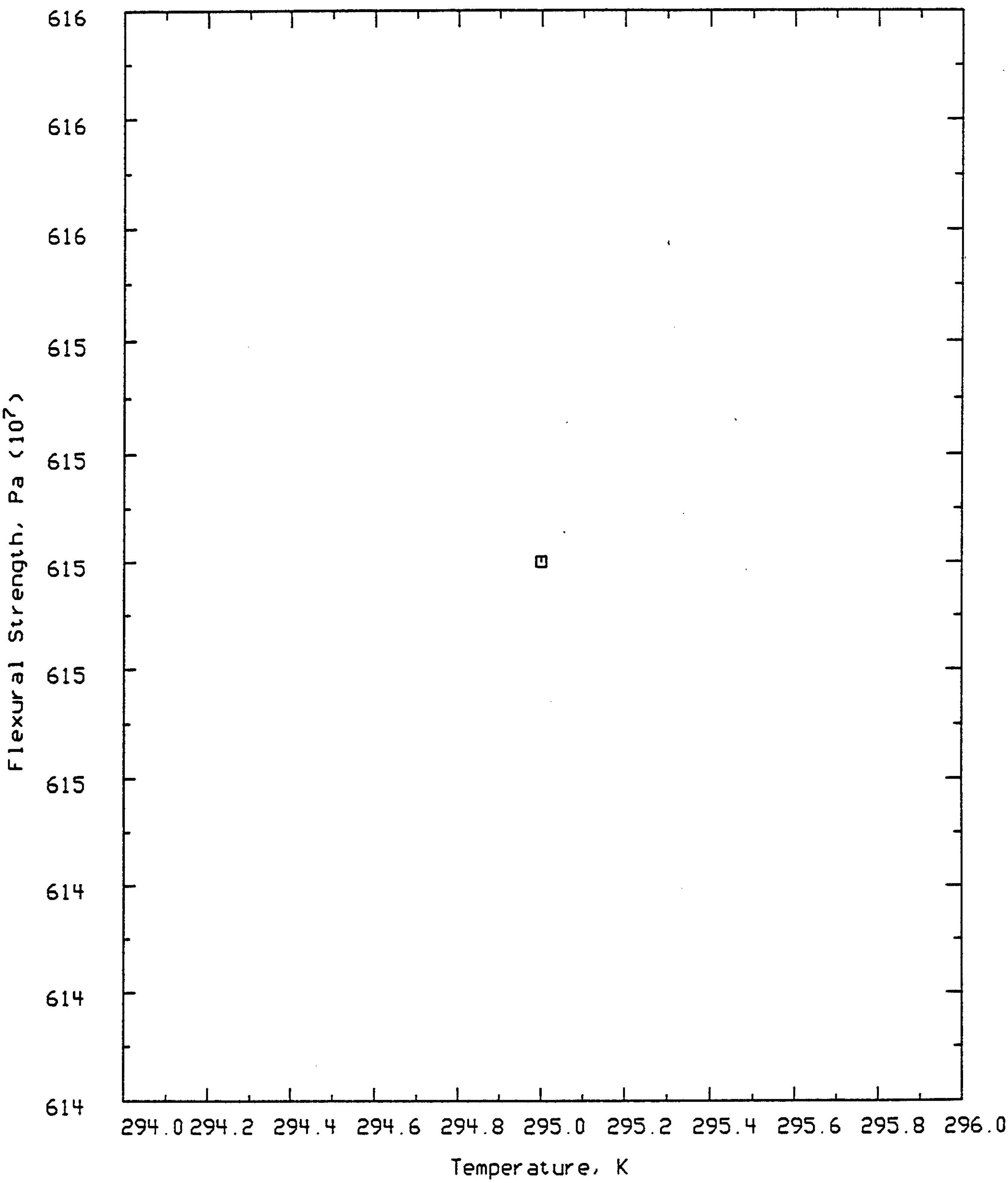

Figure 211 Flexural Strength of Silicon: Ga doped

MATERIAL: Silicon: Ga doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 212

****

Composition

3e+16 cm^{-3} Gallium Dopant Concentration

Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, p-type

Specimen Identification

Orientation With Respect To Material : (100) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure
Axisymmetric bending method employing pneumatic loading.
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Argon Environment

Measured/Evaluated Properties

X : Temperature K
Y : Flexural Strength Pa

Data Points :

X	Y	Remarks:
2.950e+02	6.310e+09	Standard Deviation = 410 MPa

Comments on Data

Number of specimens was at least 15.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

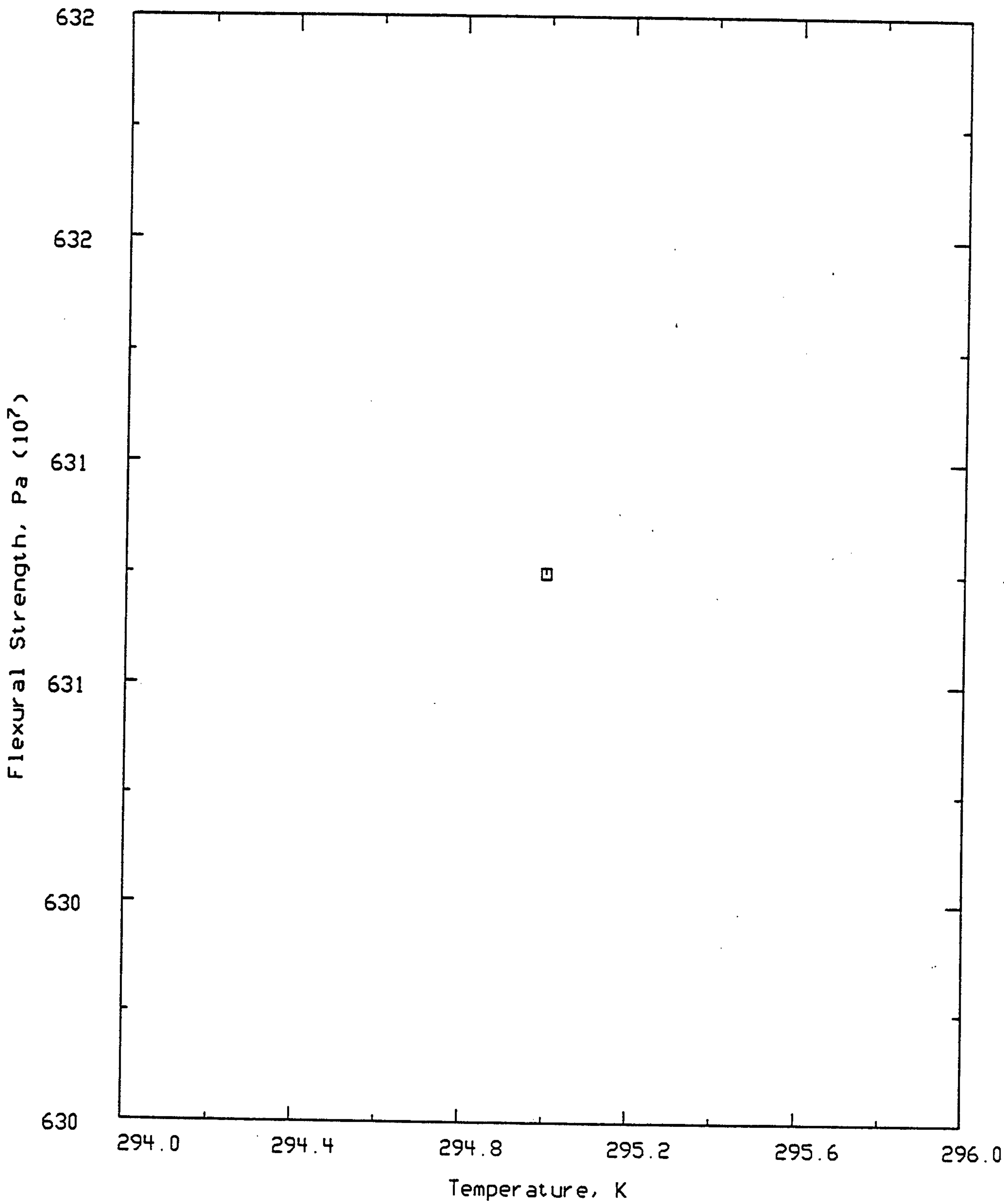

Figure 212 Flexural Strength of Silicon: Ga doped

MATERIAL: Silicon: Ga doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 213

****

Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, p-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure
Axisymmetric bending method employing pneumatic loading.
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.
Dopant concentrations were determined from standard electrical property measurements.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X	: Gallium Dopant Concentration	m^{-3}
Y	: Flexural Strength	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1	Remarks:
1.000e+21	4.000e+07	2.950e+02	S.D. = 3.9 MPa, As-Cut Condition
3.000e+24	5.400e+07	2.950e+02	S.D. = 4.1 MPa
1.000e+21	6.400e+07	2.950e+02	S.D. = 4.2 MPa, As-Cut + Ground
3.000e+24	7.300e+07	2.950e+02	S.D. = 6.3 MPa
1.000e+21	5.840e+09	2.950e+02	S.D. = 440 MPa, Chem. Etched
2.500e+22	6.150e+09	2.950e+02	S.D. = 430 MPa
3.000e+23	6.410e+09	2.950e+02	S.D. = 470 MPa
1.000e+24	7.350e+09	2.950e+02	S.D. = 540 MPa
3.000e+24	8.800e+09	2.950e+02	S.D. = 480 MPa

Comments on Data

The number of specimens was at least 15 per condition or dopant concentration.
High concentration of gallium dopant noticeably enhance the flexural strength.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

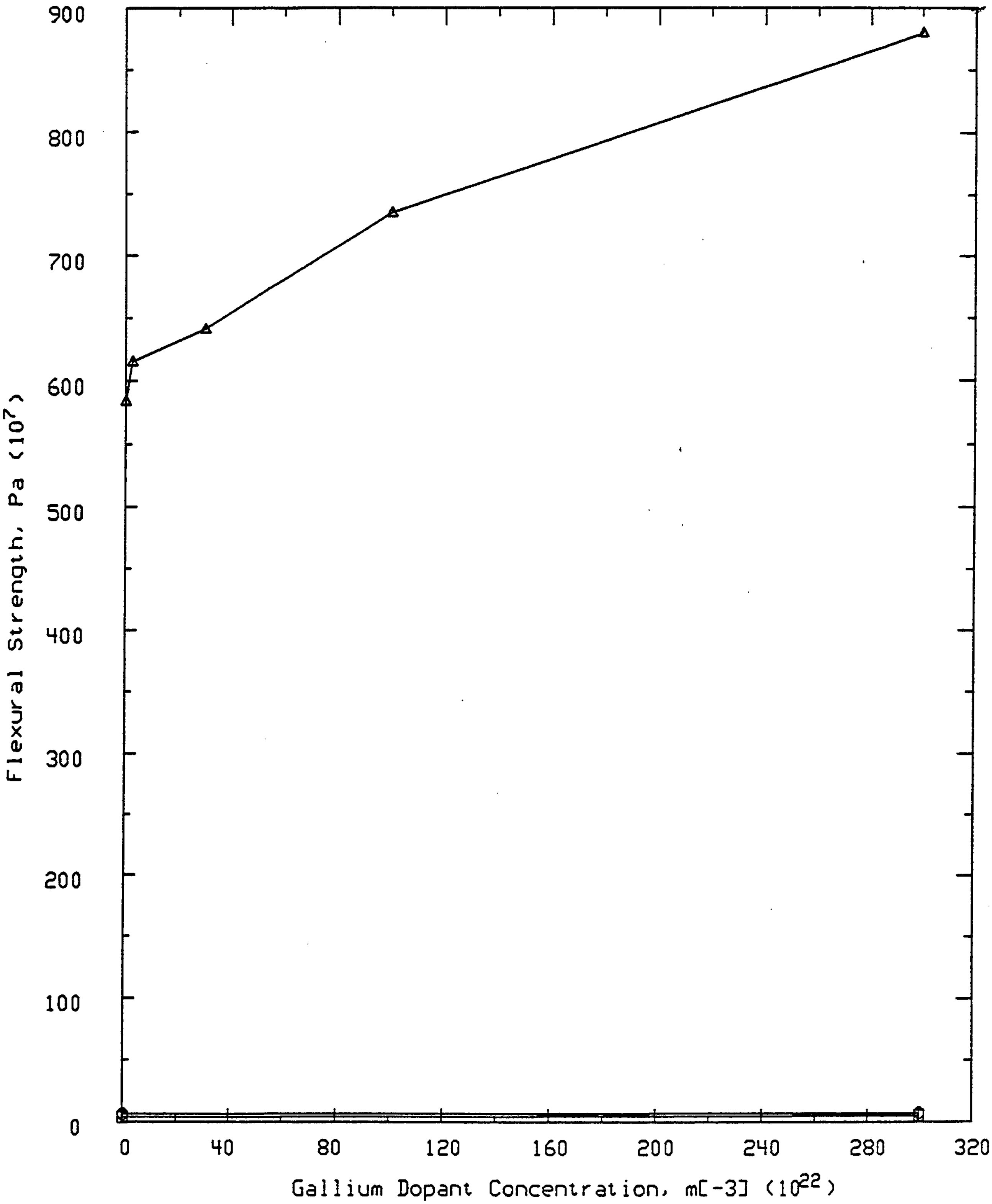

Figure 213 Flexural Strength of Silicon: Ga doped

MATERIAL: Silicon: P doped	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Flexural Strength	DATA SET 214

****

Composition

5e+14	cm^{-3}	Phosphorus Dopant Concentration
2e+16	cm^{-3}	Oxygen Concentration

Material Preparation

Crystal Growing Method :
Crucibleless zonal melting

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, n-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure Test
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X : Temperature	K
Y : Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	6.000e+09	Standard Deviation = 530 MPa

Comments on Data

Number of specimens was at least 15.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

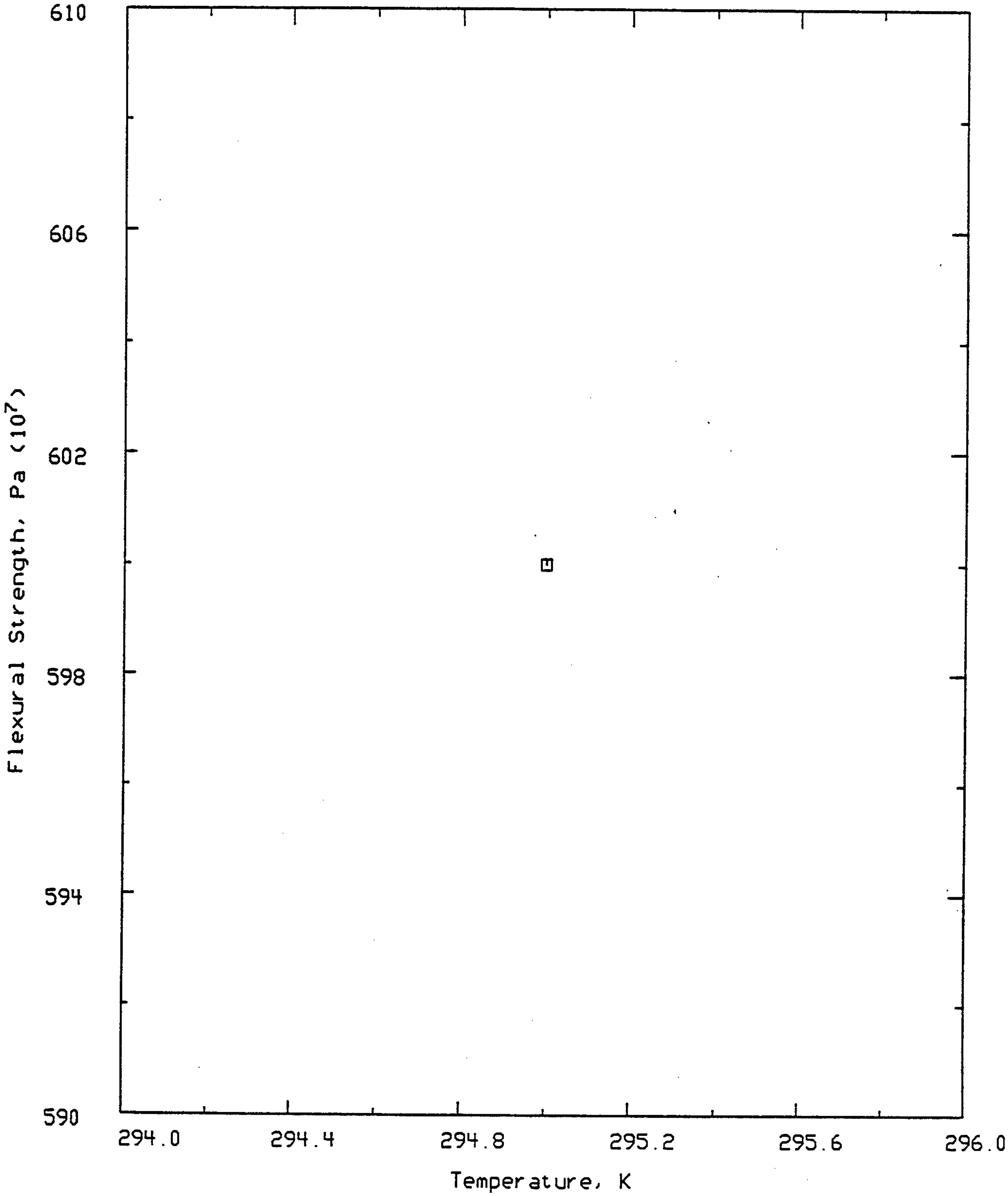

Figure 214 Flexural Strength of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
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Composition

4e+17	cm^{-3}	Oxygen Concentration
9e+15	cm^{-3}	Phosphorus Dopant Concentration

Material Preparation

Crystal Growing Method :

Czochralski

Additional Preparation/Conditioning

Surface Treatment :

Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).

This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation density = 1.0e+4 cm[-2]; n-type material

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Pneumatically Loaded Wafer Flexure Test

A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.

Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	6.050e+09	Standard Deviation = 480 MPa

Comments on Data

Number of specimens was at least 15.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

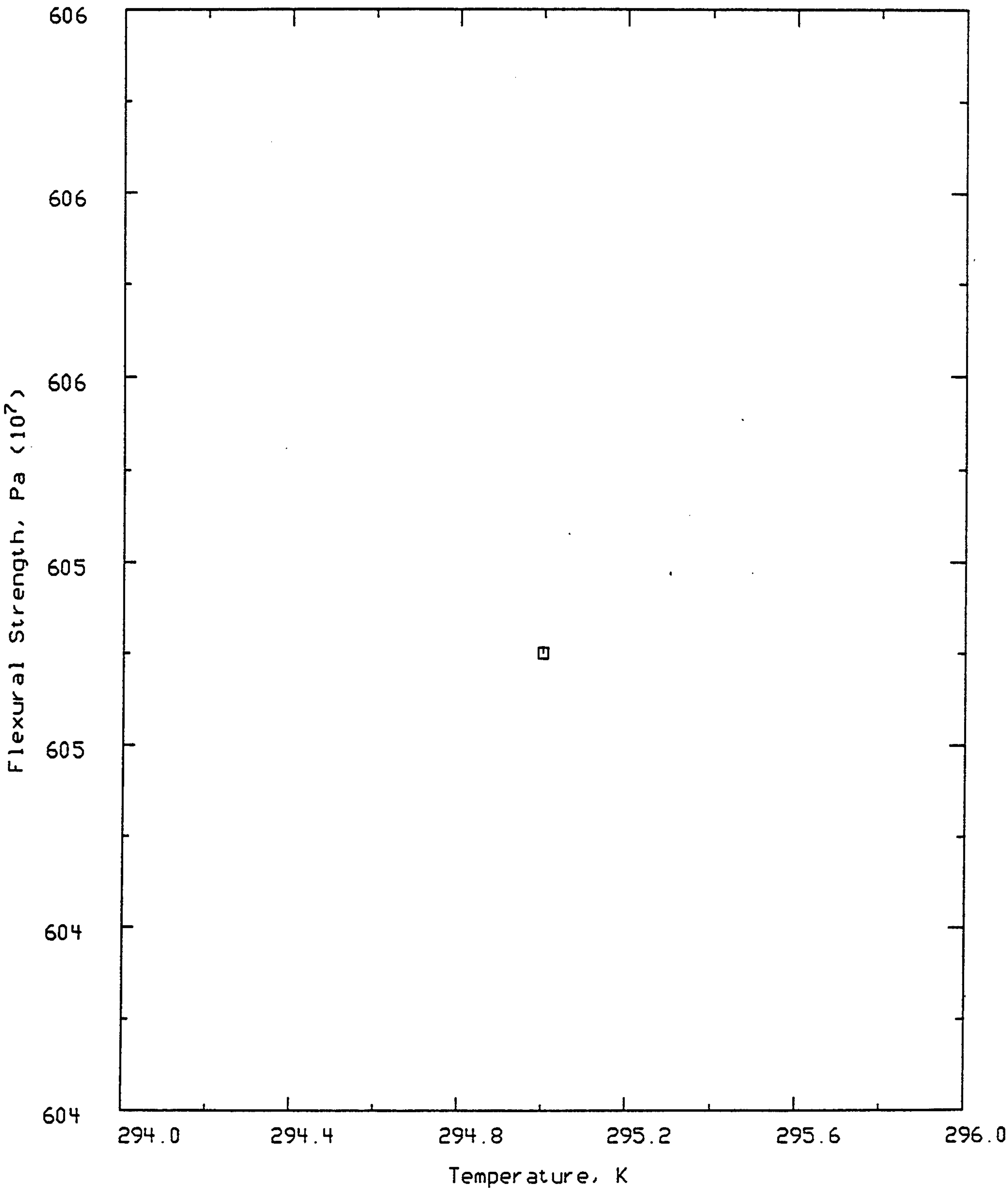

Figure 215 Flexural Strength of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Flexural Strength

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PURDUE UNIVERSITY
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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, n-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure Test
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.
Dopant concentrations were determined from standard electrical property measurements.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa
Z1	: Phosphorus Dopant Concentration	m^{-3}

Data Points :

X	Y	Z1	Remarks:
2.950e+02	4.200e+07	9.000e+21	S.D. = 3.7 MPa, As-Cut Condition
2.950e+02	4.800e+07	2.000e+25	S.D. = 5.1 MPa
2.950e+02	5.500e+07	9.000e+21	S.D. = 4.9 MPa, As-Cut + Ground
2.950e+02	7.600e+07	2.000e+25	S.D. = 6.9 MPa
2.950e+02	6.110e+09	9.000e+21	S.D. = 420 MPa, Chemically Etched
2.950e+02	5.840e+09	1.500e+22	S.D. = 360 MPa
2.950e+02	6.370e+09	1.500e+24	S.D. = 540 MPa
2.950e+02	7.600e+09	8.000e+24	S.D. = 570 MPa
2.950e+02	9.300e+09	2.000e+25	S.D. = 740 MPa

Comments on Data

Number of specimens measured was at least 15 per condition or dopant concentration.

High concentrations of phosphorus dopant noticeably enhance the flexural strength.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

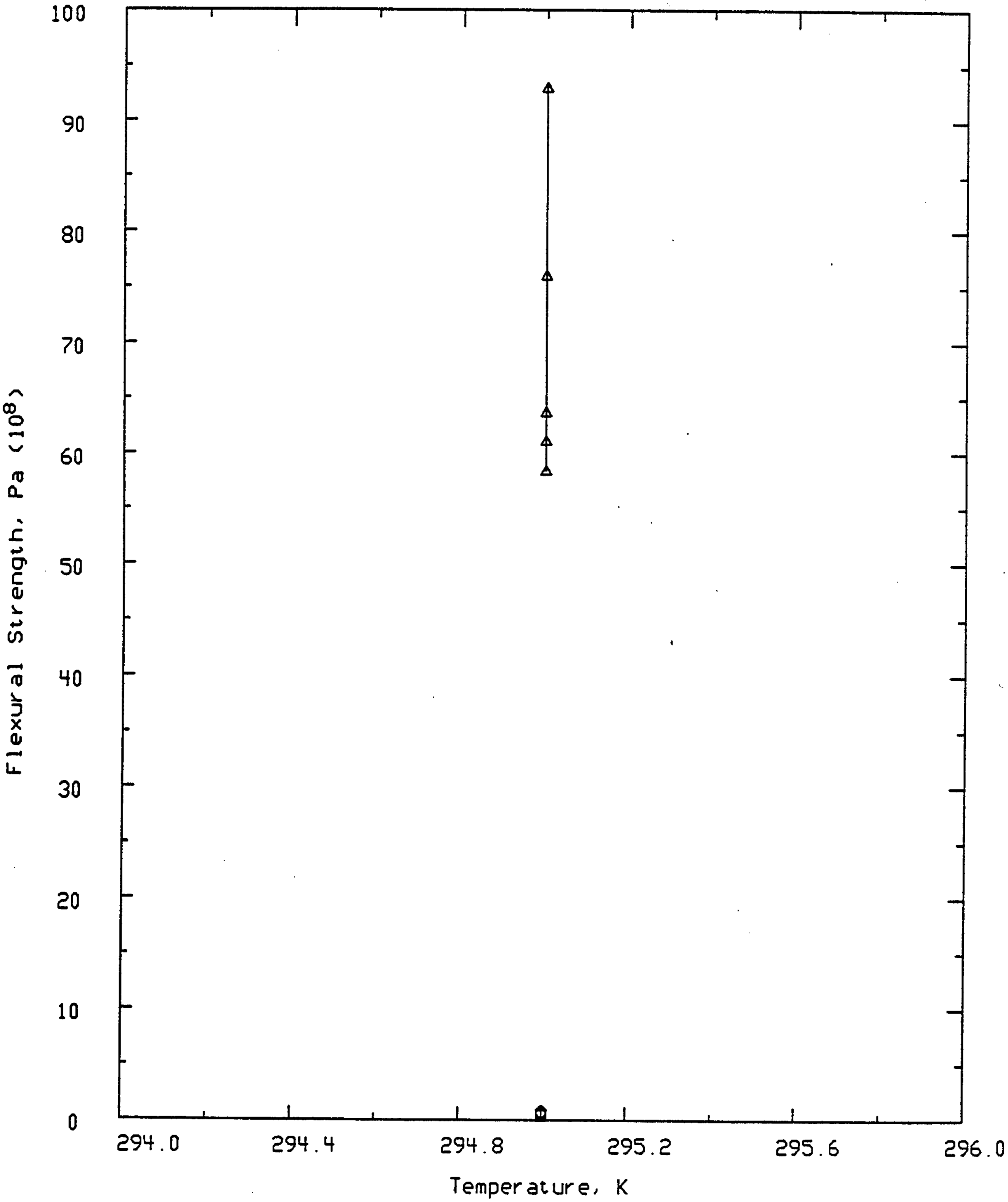

Figure 216 Flexural Strength of Silicon: P doped

MATERIAL: Silicon: Sb doped

PROPERTY: Flexural Strength

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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).
This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material, n-type

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :
Pneumatically Loaded Wafer Flexure Test
A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.
Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.
Dopant concentrations were determined from standard electrical property measurements.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X : Antimony Dopant Concentration	m^{-3}
Y : Flexural Strength	Pa
Z1 : Temperature	K

Data Points :

X	Y	Z1	Remarks:
3.000e+21	4.300e+07	2.950e+02	S.D. = 3.9 MPa, As-Cut Condition
3.000e+24	4.400e+07	2.950e+02	S.D. = 3.6 MPa
3.000e+21	7.000e+07	2.950e+02	S.D. = 5.8 MPa, As-Cut + Ground
3.000e+24	6.600e+07	2.950e+02	S.D. = 4.9 MPa
3.000e+21	5.850e+09	2.950e+02	S.D. = 340 MPa, Chemically Etched
6.000e+22	5.790e+09	2.950e+02	S.D. = 480 MPa
3.000e+23	5.230e+09	2.950e+02	S.D. = 300 MPa
2.000e+24	5.050e+09	2.950e+02	S.D. = 290 MPa
3.000e+24	4.460e+09	2.950e+02	S.D. = 230 MPa

Comments on Data

The number of specimens was at least 15 per surface condition and dopant concentration.
High concentrations of antimony dopant noticeably reduced the flexural strength.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

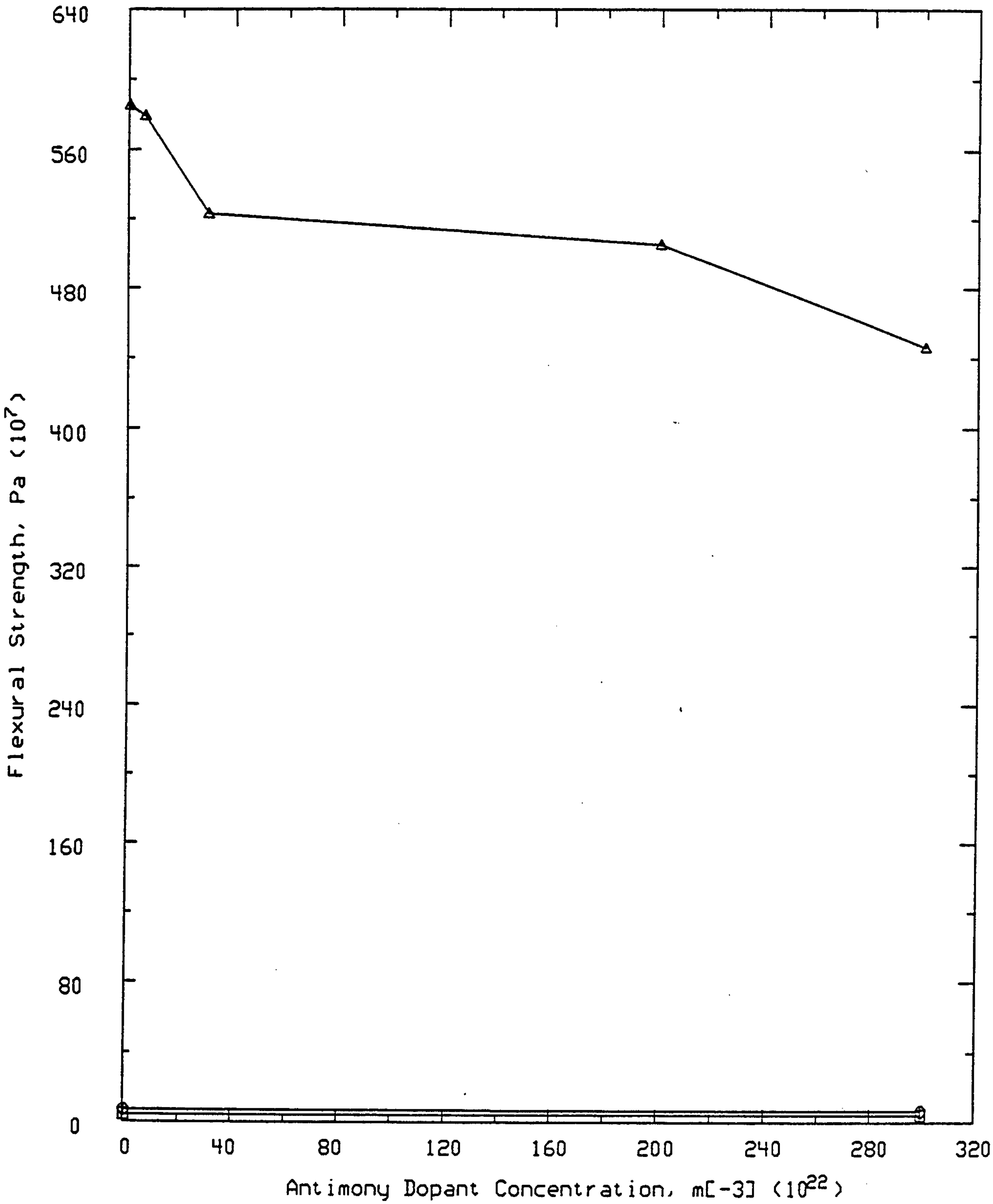

Figure 217 Flexural Strength of Silicon: Sb doped

MATERIAL: Silicon: Sn doped

PROPERTY: Flexural Strength

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PURDUE UNIVERSITY
DATA SET 218

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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :

Subsequent to cutting the wafers with a diamond saw, both surfaces were ground with M-28(boron carbide) powder to remove a layer from 60 to 100 microns thick, and then were chemically polished (conc. HNO(3):conc. HF=2:1) to remove an additional 180 micron (approx.).

This surface treatment ensured virtually complete removal of surface damage.

Material Microstructure

Dislocation-free material

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Pneumatically Loaded Wafer Flexure Test

A no-contact loading method utilized gas pressure loading on a silicon wafer freely supported by a ring support. A vacuum lubricant was applied to the wafer-ring interface. Gas pressures up to 20 MPa permitted application of a total load amounting to 12 kN to the surface of rings up to 90mm in diameter.

Fracture strength was computed from pressure, diameter, and thickness by applying simple theory.

Dopant concentrations were determined from standard electrical property measurements.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Vacuum Environment

Measured/Evaluated Properties

X	: Tin Dopant Concentration	m^{-3}
Y	: Flexural Strength	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1	Remarks:
2.000e+23	6.400e+07	2.950e+02	S.D. = 4.1 MPa, As-Cut Condition
7.000e+23	6.700e+07	2.950e+02	S.D. = 5.3 MPa
2.000e+23	7.400e+07	2.950e+02	S.D. = 560 MPa, As-Cut + Ground
7.000e+23	7.500e+07	2.950e+02	S.D. = 4.2 MPa
2.000e+23	4.500e+09	2.950e+02	S.D. = 510 MPa, Chemically Etched
7.000e+23	4.350e+09	2.950e+02	S.D. = 450 MPa

Comments on Data

The number of specimens was at least 15 per surface condition and dopant concentration.
High concentrations of tin dopant noticeably reduced the flexural strength.

Reference

FACTORS AFFECTING THE BULK STRENGTH OF SILICON SINGLE CRYSTALS.
Osvenskii, V. B. Turovskii, B. M.
Mezhennyi, M. V. Sokolova, E. L.
Stolyarov, O. G.
IZV. AKAD. NAUK SSSR, NEORG. MATER.
21 (3), 357-61, 1985.
(FOR ENGLISH TRANSLATION SEE INORG. MATER.,
21 (3), 299-302, 1985)

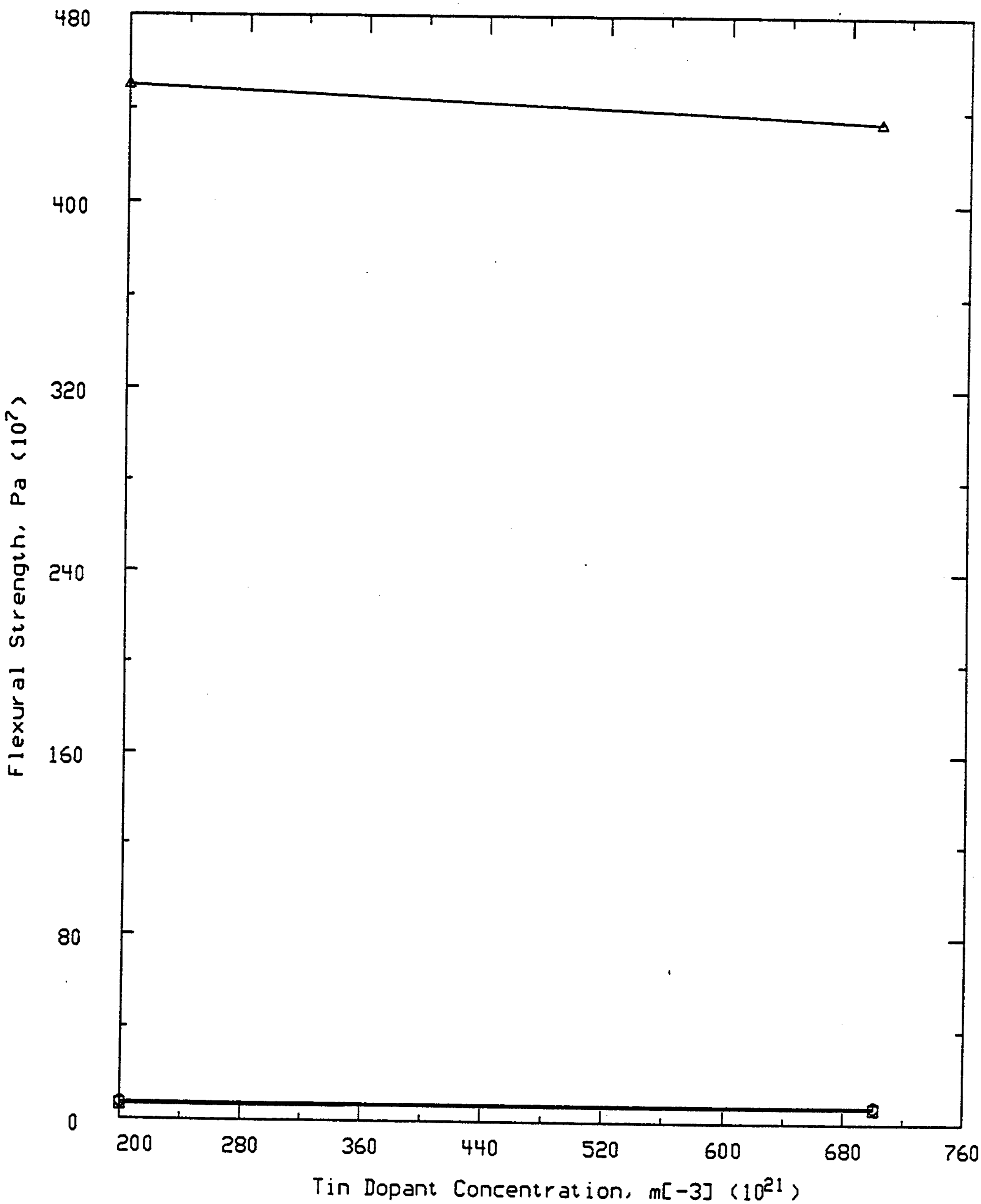

Figure 218 Flexural Strength of Silicon: Sn doped

MATERIAL: Silicon, p-type

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 219

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Material Preparation

Crystal Growing Method :
Float-Zoned

Additional Preparation/Conditioning

Surface Treatment :
As-received wafers had one mirror finish surface (tension surface) and one deep etched surface (compression surface). The deep etched surface was heavily etched with CP4 (HF:HNO(3):glacial acetic acid = 3:5:3).

Specimen Identification

Number/Name : Float-zone p-type silicon, hydrogen-anneal effect.
Orientation With Respect To Material : (100) Plane

Additional Properties

Electrical Properties :

Electrical Resistivity	>30	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers.
Circular aluminum platform had 5 mm diameter hole with a beveled edge to provide concentric support.
Load was applied by a 5 mm ball attached to an Instron machine.
Crosshead speed was 100 micron/min.
Fracture load was converted to flexure strength (tensile surface stress at fracture) using elastic bending theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Hydrogen Environment
Descriptors-Numerical :

Annealing Temperature	1250	°C

Measured/Evaluated Properties

X : Annealing Time	s
Y : Flexural Strength	Pa

Data Points :

X	Y	Remarks:
0.000e+00	2.000e+09	S.D. = 0.16 GPa, No. specimens = 8
5.400e+03	4.200e+09	S.D. = 0.85 GPa, No. specimens = 8

Comments on Data

Fracture strength enhancement is thought to be due to annealing of imperfections on the wafer backface(compression side).

Reference

FRACTURE OF SILICON WAFERS.
McLaughlin, J. C. Willoughby, A. F. W.
J. CRYST. GROWTH
85, 83-90, 1987.

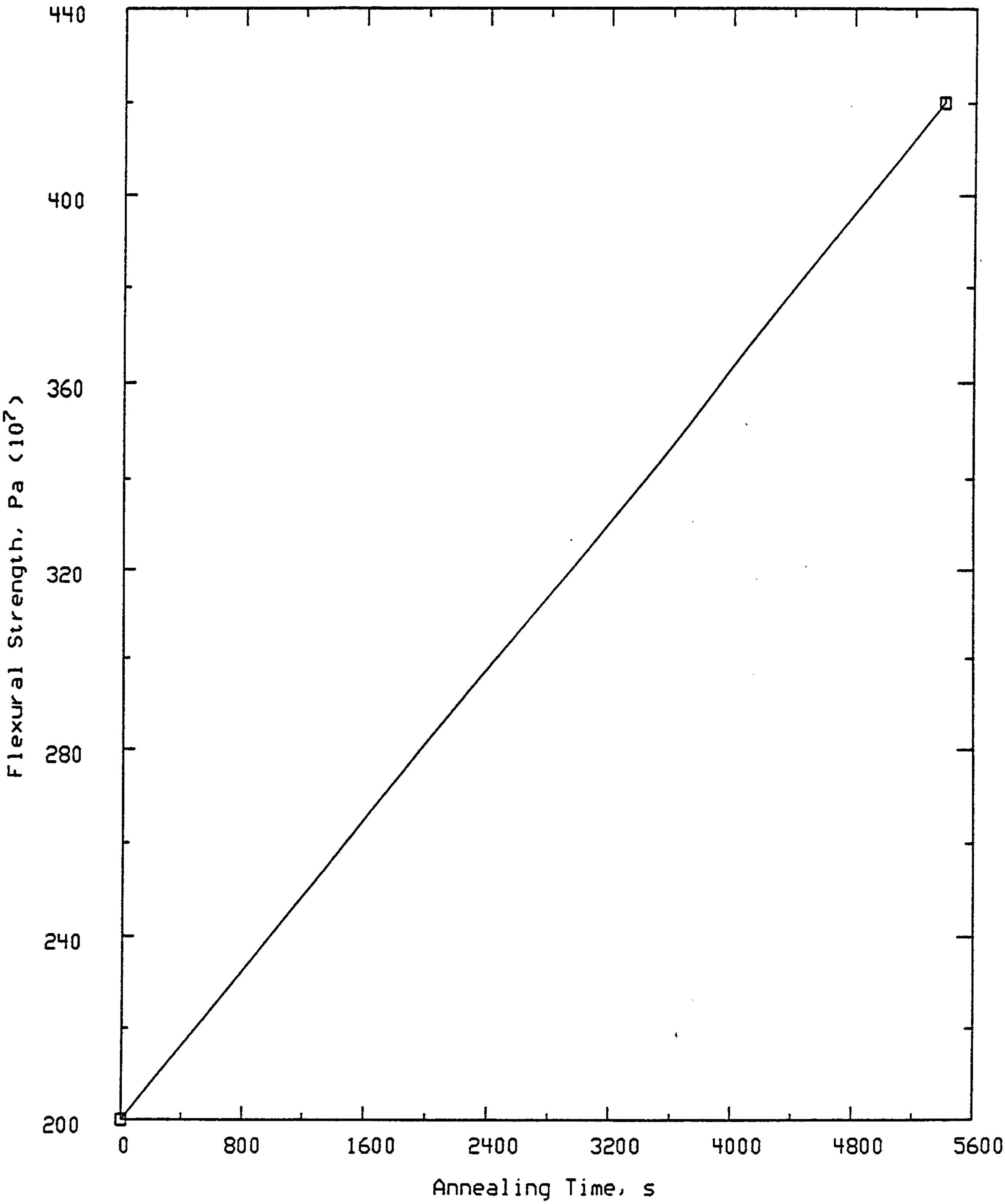

Figure 219 Flexural Strength of Silicon, p-type

MATERIAL: Silicon, p-type

PROPERTY: Flexural Strength

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PURDUE UNIVERSITY
DATA SET 220

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Material Preparation

Crystal Growing Method :
Float-Zoned

Additional Preparation/Conditioning

Surface Treatment :
As-received wafers had one mirror finish surface (tension surface) and one deep etched surface (compression surface). The deep etched surface was heavily etched with CP4 (HF:HNO(3):glacial acetic acid = 3:5:3).

Specimen Identification

Number/Name : Float-zone p-type silicon, oxidation effect
Sample Series A, B, C, D, E, F, G, and H.
Orientation With Respect To Material : (100) Plane

Additional Properties

Electrical Properties :

Electrical Resistivity	30	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers.
Circular aluminum platform had 5 mm diameter hole with a beveled edge to provide concentric support.
Load was applied by a 5 mm ball attached to an Instron machine.
Crosshead speed was 100 micron/min.
Fracture load was converted to flexure strength (tensile surface stress at fracture) using elastic bending theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Oxidation Treatment
Descriptors-Numerical :

Annealing Temperature	1250	°C

Descriptors-Textual :
Dry oxide layers 0.70 micron in thickness were grown on the wafers.

Measured/Evaluated Properties

X : Oxidation Time s

Y : Flexural Strength Pa

Data Points :

X	Y	Remarks:
0.000e+00	2.000e+09	S.D.=0.15 GPa,Control Series
5.760e+04	3.300e+09	S.D.=0.39 GPa,CP + O
5.760e+04	2.400e+09	S.D.=0.40 GPa,CP + O + E
5.760e+04	3.000e+09	S.D.=0.21 GPa,O
5.760e+04	2.000e+09	S.D.=0.07 GPa,O + E
1.152e+05	3.200e+09	S.D.=0.51 GPa,O + E + O
1.152e+05	2.000e+09	S.D.=0.48 GPa,O(2) + E(2)
6.584e+04	2.100e+09	S.D.=0.56 GPa,O + E + PO

Comments on Data

Surface-treatment(oxidation) test series are identified by:

CP = Chemical Polish
O = Oxidation
PO = Partial Oxidation
E = Etched to remove oxide

Number of specimens was eight per test series.
An oxide layer 0.70 micron thickness on the compression side is observed to increase the fracture strength.

Reference

FRACTURE OF SILICON WAFERS.
McLaughlin, J. C. Willoughby, A. F. W.
J. CRYST. GROWTH
85, 83-90, 1987.

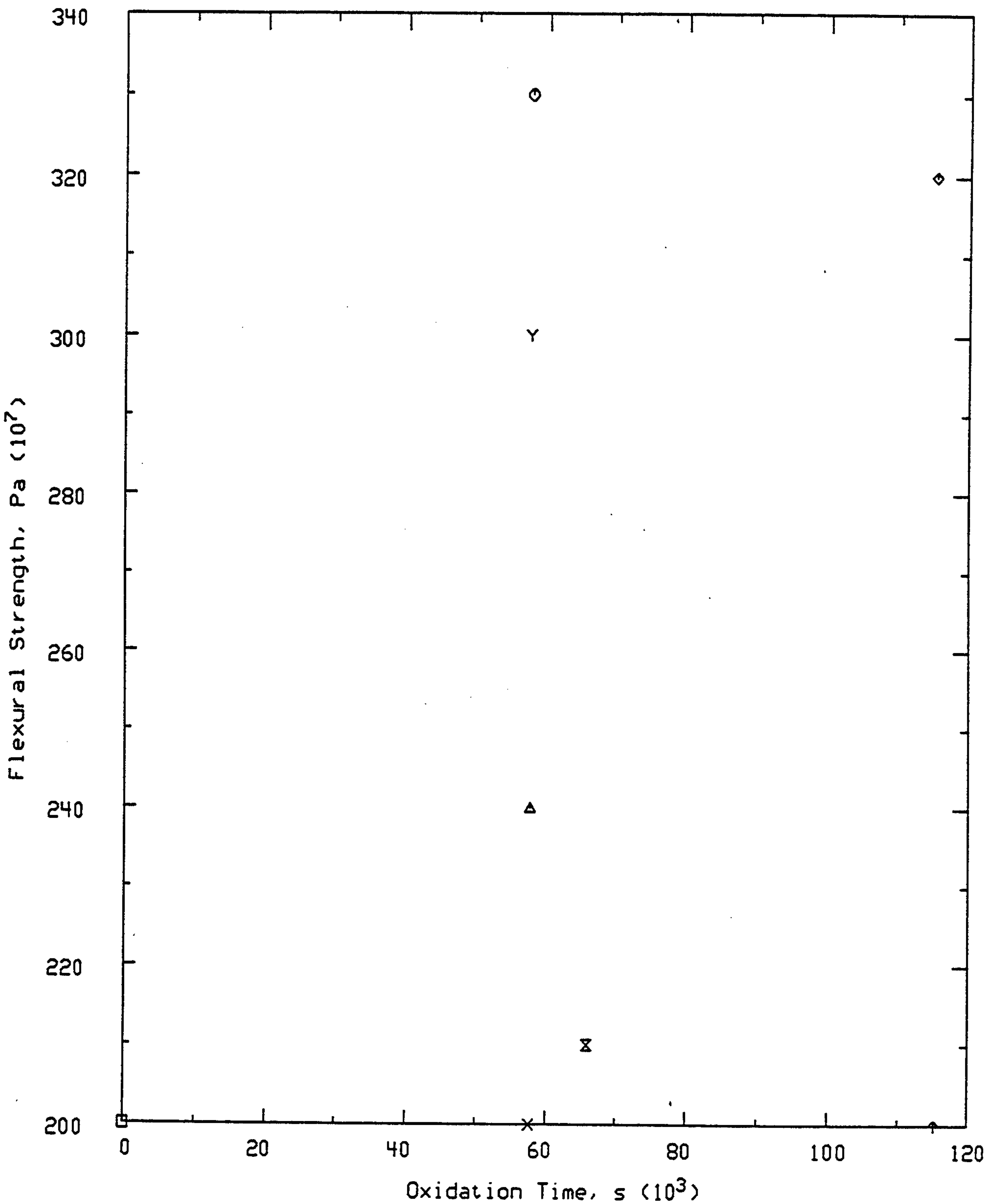

Figure 220 Flexural Strength of Silicon, p-type

MATERIAL: Silicon, p-type	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Flexural Strength	DATA SET 221

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Material Preparation

Crystal Growing Method :
Float-Zoned

Additional Preparation/Conditioning

Surface Treatment :
As-received wafers had one mirror finish surface (tension surface) and one deep etched surface (compression surface). The deep etched surface was heavily etched with CP4 (HF:HNO(3):glacial acetic acid = 3:5:3).

Specimen Identification

Number/Name : Float-Zone p-type silicon, implantation and RTA effect
Orientation With Respect To Material : (100) Plane

Additional Properties

Electrical Properties :

Electrical Resistivity	>30	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers.
Circular aluminum platform had 5 mm diameter hole with a beveled edge to provide concentric support.
Load was applied by a 5 mm ball attached to an Instron machine.
Crosshead speed was 100 micron/min.
Fracture load was converted to flexure strength (tensile surface stress at fracture) using elastic bending theory.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Ion Implantation
Descriptors-Numerical :

Annealing Temperature	1250	°C

Descriptors-Textual :
Ion-implantation parameters: Ge(+) with 1.0e+15 cm[-2] dosage.
Ion-implantation parameters: B(+) with 1.0e+15 cm[-2]
Ion-implantation parameters: B(+) with 1.0e+16 cm[-2]
Ion-implantation parameters: Sb(+) with 3.76e+14 cm[-2]
Ion-implantation parameters: Sb(+) with 3.76e+15 cm[-2]
Implantation was followed by rapid thermal anneal(RTA)

Measured/Evaluated Properties

X : Annealing Time — s

Y : Flexural Strength — Pa

Data Points :

X	Y	Remarks:
1.770e+04	2.300e+09	S.D.=0.1 GPa,B(+) 1.0e+15 cm[-2] + RTA
1.770e+04	2.200e+09	S.D.=0.4 GPa,B(+) 1.0e+16 cm[-2] + RTA
1.770e+04	2.200e+09	S.D.=0.1 GPa,Sb(+) 3.76e+14 cm[-2] + RTA
1.770e+04	2.300e+09	S.D.=0.2 GPa,Sb(+) 3.76e+15 cm[-2] + RTA
1.770e+04	1.900e+09	S.D.=0.6 GPa,Ge(+) 1.0e+15 cm[-2]
1.770e+04	2.100e+09	S.D.=0.4 GPa,Ge(+) 1.0e+15 cm[-2] + RTA
1.770e+04	2.200e+09	S.D.=0.1 GPa,Ge(+) + B(+) 1.0e+15 cm[-2] + RTA
1.770e+04	1.900e+09	S.D.=0.4 GPa, RTA only

Comments on Data

Implantation followed by rapid thermal anneal(RTA) appears to enhance the fracture strength slightly.
Number of specimens was eight per test series.

Reference

FRACTURE OF SILICON WAFERS.
McLaughlin, J. C. Willoughby, A. F. W.
J. CRYST. GROWTH
85, 83-90, 1987.

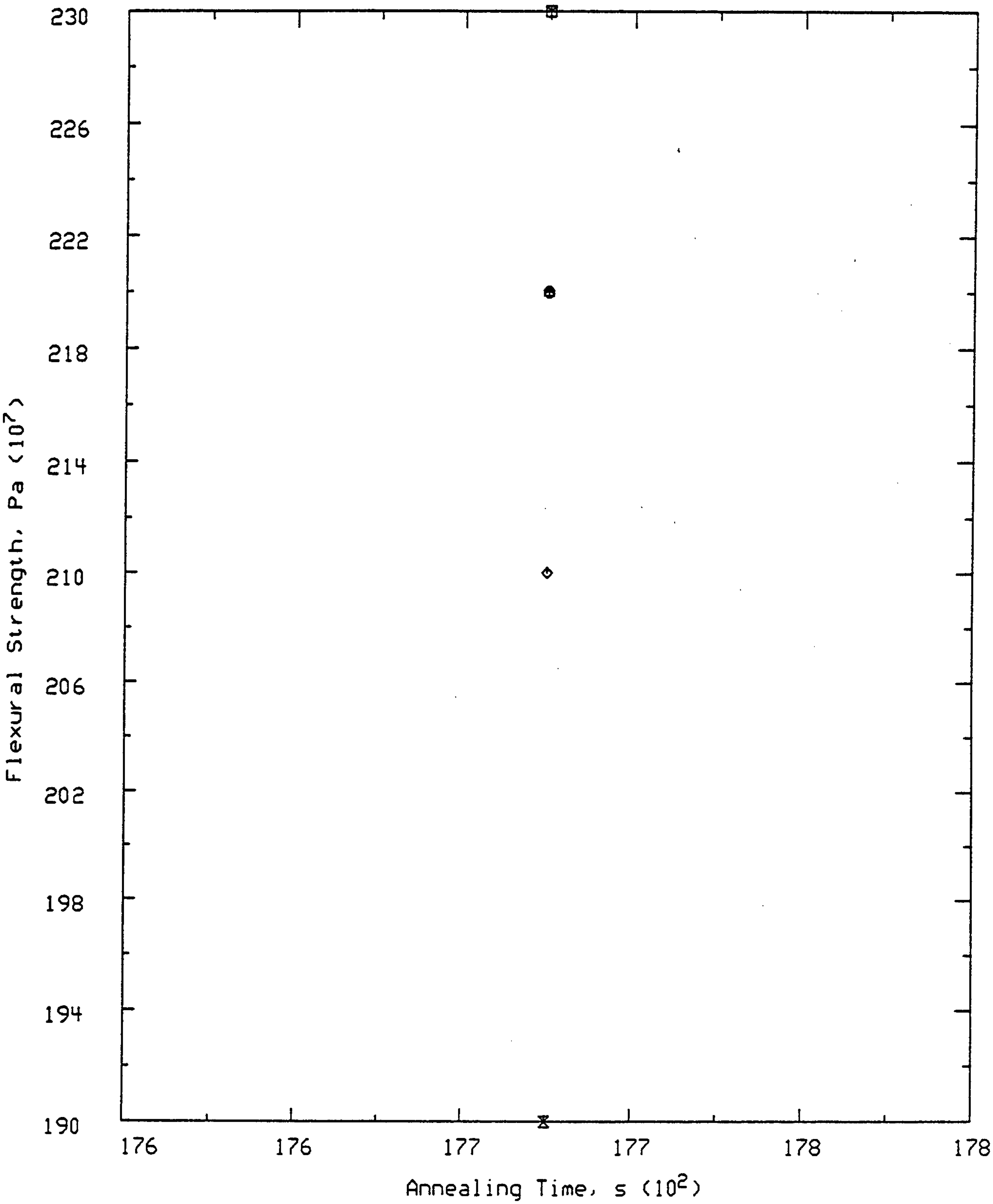

Figure 221 Flexural Strength of Silicon, p-type

MATERIAL: Silicon

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 222

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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Wafers polished on both surfaces to a mirror-finish with silica gel.

Material Microstructure

Single crystalline material.

Panel/Billet/Lot/Batch Number

Lot 1

Specimen Identification

Number/Name : Lot 1, Series A and B specimens.
Additional Identifiers :
Wafer surfce orientation was either (100) or (111).

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers
Parameters-Textual :
Circular aluminum platform had a 5 mm diameter hole with a slightly rounded edge to provide concentric support.
Load was transmitted to wafer by means of a spherical ball (ball diameter either 1.2 or 5.0 mm). Load was increased incrementally to fracture.
Flexure strength was calculated as the stress at fracture in the tensile surface using elastic bending theory.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	3.000e+09	S.D.=0.87 GPa,(100) Surface,1.2 mm Ball Radius

2.950e+02	3.100e+09	S.D.=1.4 GPa, (100) Surface,5.0 mm Ball Radius
2.950e+02	2.100e+09	S.D.=0.8 GPa, (111) Surface,1.2 mm Ball Radius
2.950e+02	2.800e+09	Standard Deviation Overall=1.2 GPa

Comments on Data

Ball diameter had no measurable effect on fracture strength.
Fracture strength for (100) surface is about 50 percent higher than for (111) surface, but the statistical significance is uncertain.
Presence of edge flaws was inconsequential for this test method.

Reference

CRITICAL STRESS IN SILICON BRITTLE FRACTURE, AND EFFECT OF ION IMPLANTATION AND OTHER SURFACE TREATMENTS.
Hu, S. M.
J. APPL. PHYS.
53 (5), 3576-80, 1982.

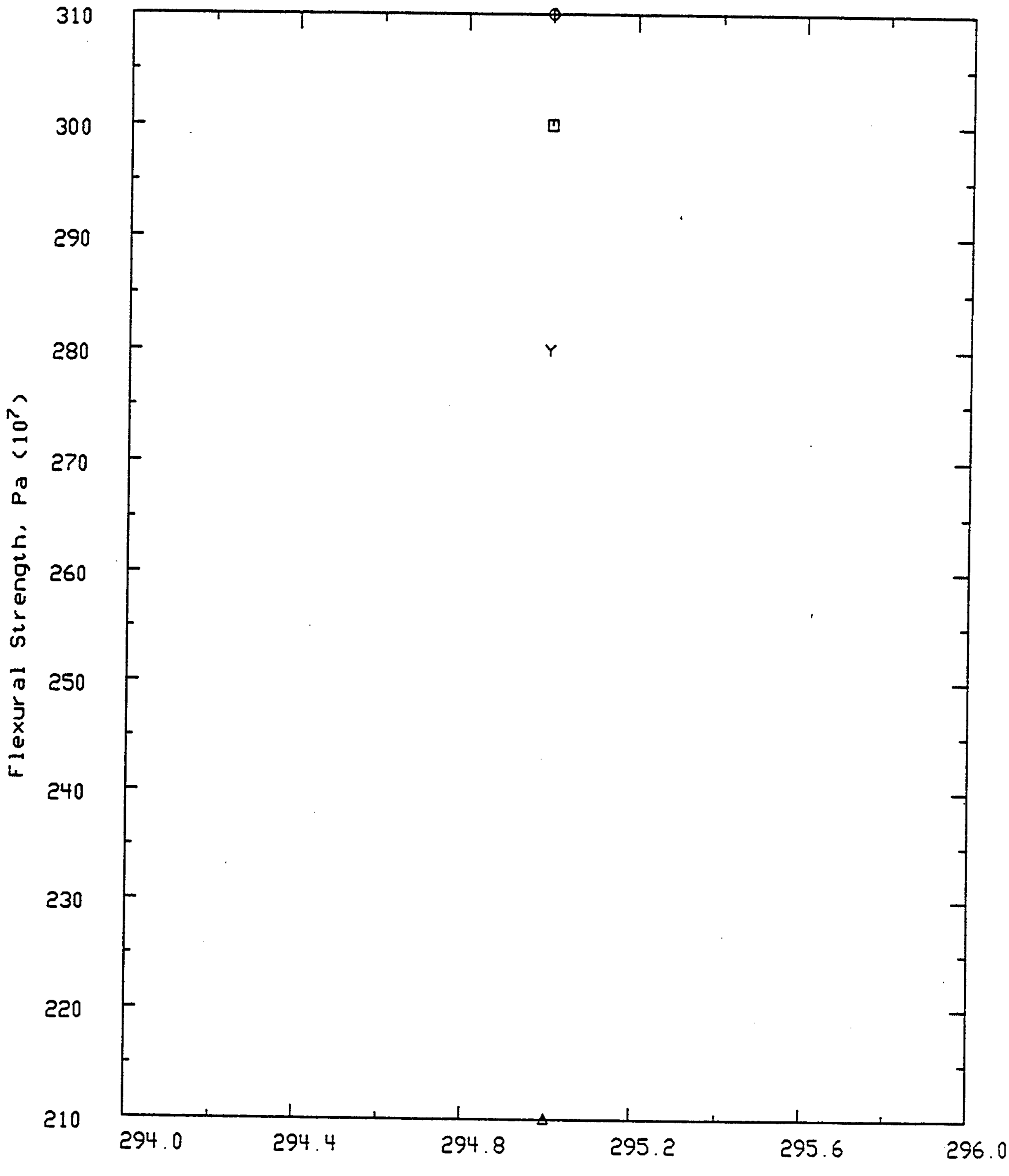

Figure 222 Flexural Strength of Silicon

MATERIAL: Silicon

PROPERTY: Flexural Strength

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PURDUE UNIVERSITY
DATA SET 223

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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :

Wafers were polished on both surfaces to a mirror-like finish with silica gel.

Subsequent surface treatments:

Lot 1, Series A and B: control
Lot 1, Series C: quartz overlay
Lot 2, Series K: control
Lot 2, Series D: lapped with 12.5 micron alumina (4.5 micron damage depth)
Lot 2, Series E: ground with 400 grit diamond (9 micron damage depth)
Lot 2, Series F: ground with 1200 grit diamond (3 micron damage depth)
Lot 2, Series G: ground with 1200 grit diamond (compression side)
Lot 2, Series H: polysilicon overlay (2 micron depth, 200 nm grain size)
Lot 2, Series I: implantation with argon ions (150 keV, 1.0e+16 ions cm[-2] dosage)
Lot 2, Series J: implantation + anneal in nitrogen 1 hour at 900 C
Lot 2, Series N: implantation + 2-step anneal
Lot 2, Series L: control + 2-step anneal

Material Microstructure

Single crystalline material.

Panel/Billet/Lot/Batch Number

Lots 1 and 2, each from a different ingot

Specimen Identification

Number/Name : Lot 1, Series A, B, and C.
Lot 2, Series D, E, F, G, H, I, J, K, L, and N

Orientation With Respect To Material : (100) Plane

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers
Parameters-Textual :
Circular aluminum platform had a 5 mm diameter hole with a slightly rounded edge to provide concentric support.
Load was transmitted to wafer by means of a spherical ball (ball diameter either 1.2 or 5.0 mm). Load was increased incrementally to fracture.
Flexure strength was calculated as the stress at fracture in the tensile surface using elastic bending theory.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength	Pa

Data Points :

X	Y	Remarks:
2.950e+02	2.800e+09	S.D.=1.2 GPa, Series A and B
2.950e+02	2.400e+09	S.D.=0.54 GPa, Series C
2.950e+02	1.600e+09	S.D.=0.65 GPa, Series K
2.950e+02	3.300e+08	S.D.=0.03 GPa, Series D
2.950e+02	3.100e+08	S.D.=0.05 GPa, Series E
2.950e+02	4.000e+08	S.D.=0.07 GPa, Series F
2.950e+02	1.700e+09	S.D.=0.14 GPa, Series G
2.950e+02	1.300e+09	S.D.=0.26 GPa, Series H
2.950e+02	1.600e+09	S.D.=0.8 GPa, Series I
2.950e+02	2.300e+09	S.D.=0.6 GPa, Series J
2.950e+02	1.600e+09	S.D.=0.6 GPa, Series N
2.950e+02	1.500e+09	S.D.=0.6 GPa, Series L

Comments on Data

Lot 1 had a total of 36 wafers while Lot 2 had 100.
Significant effects of surface preparation were observed in the fracture strength.

A 5 mm radius ball was used for Lot 2 wafers.

Reference

CRITICAL STRESS IN SILICON BRITTLE FRACTURE, AND EFFECT OF ION IMPLANTATION AND OTHER SURFACE TREATMENTS.
Hu, S. M.
J. APPL. PHYS.
53 (5), 3576-80, 1982.

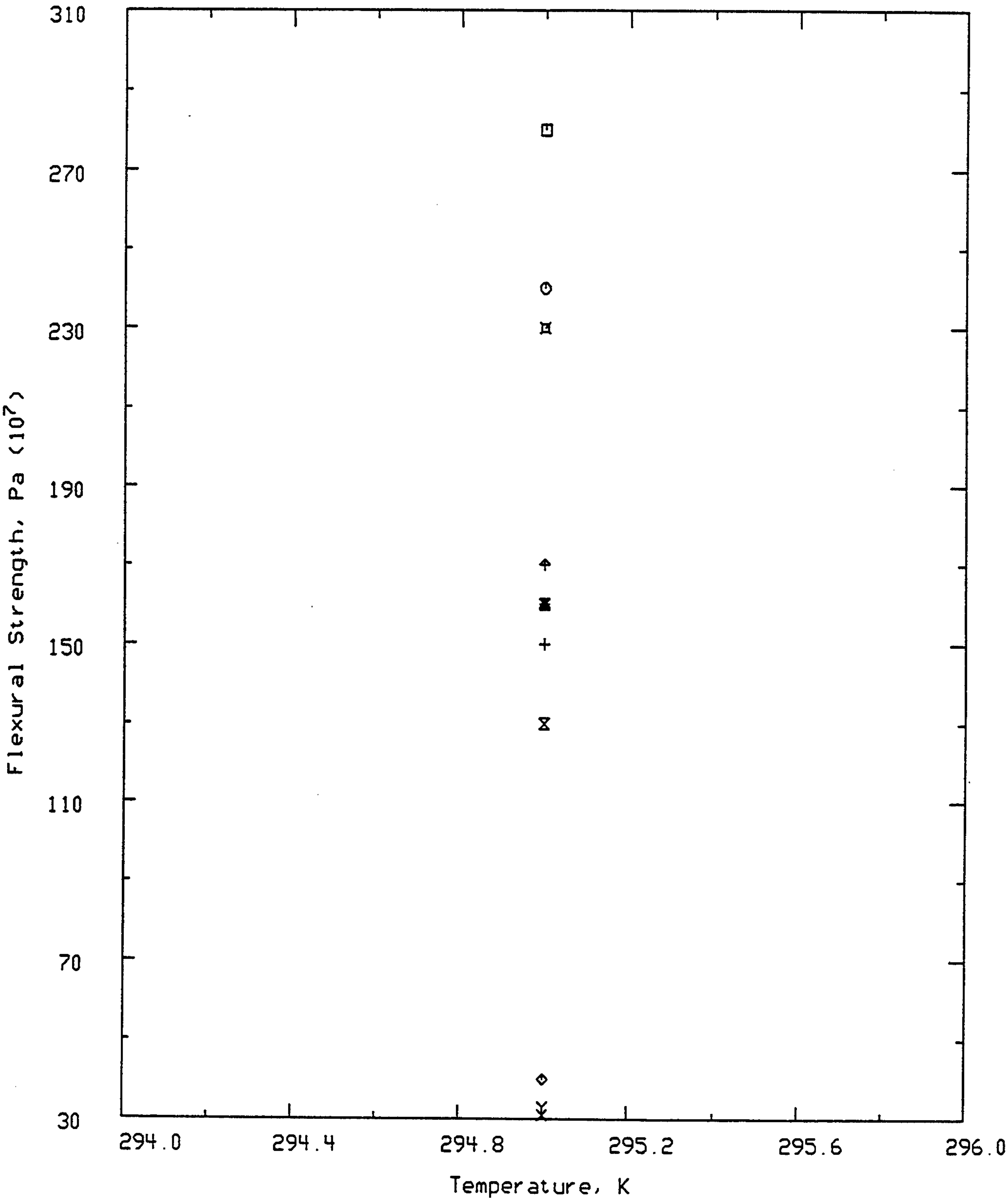

Figure 223 Flexural Strength of Silicon

MATERIAL: Silicon

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 224

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Material Preparation

Crystal Growing Method :

Both Float-Zone and Czochralski methods.

Additional Preparation/Conditioning

Surface Treatment :

As-received wafers had one mirror finish surface (tension surface) and one deep etched surface (compression surface). The deep etched surface was heavily etched with CP4 (HF:HNO(3):glacial acetic acid = 3:5:3).

Material Microstructure

Float-zoned material contained significant bulk defects (uncharacterized) while the Czochralski material did not.

Specimen Identification

Number/Name : Float-zoned and Czochralski silicon

Orientation With Respect To Material : (100) Plane

Additional Identifiers :

Original wafer thicknesses were: 381 micron Float-Zoned.

Original wafer thicknesses were: 500 micron Czochralski.

Additional Properties

Other Properties-Textual :

Electrical Resistivity: 22-31 ohm cm for Float-Zoned.

Electrical Resistivity: 2-4 ohm cm for Czochralski.

Measurement/Evaluation Method

Name/Description :

Ball-and-Ring Flexure Test for Wafers

Circular aluminum platform had 5 mm diameter hole with a beveled edge to provide concentric support.

Load was applied by a 5 mm ball attached to an Instron machine.

Crosshead speed was 100 micron/min.

Fracture load was converted to flexure strength (tensile surface stress at fracture) using elastic bending theory.

Measured/Evaluated Properties

X	: Depth Removed	m
Y	: Flexural Strength	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1	Remarks:
0.000e+00	3.700e+09	2.950e+02	FZ Silicon, 381 micron originally
7.700e-05	4.300e+09	2.950e+02	
8.700e-05	4.400e+09	2.950e+02	
1.200e-04	5.700e+09	2.950e+02	
1.660e-04	8.800e+09	2.950e+02	
1.040e-04	3.500e+09	2.950e+02	Czo. Silicon, 500 micron orignally
1.860e-04	3.400e+09	2.950e+02	
3.050e-04	4.600e+09	2.950e+02	

Comments on Data

Evidently the Czochralski silicon contains significant bulk defects that are unaffected by the compression surface etching.

Reference

FRACTURE OF SILICON WAFERS.
McLaughlin, J. C. Willoughby, A. F. W.
J. CRYST. GROWTH
85, 83-90, 1987.

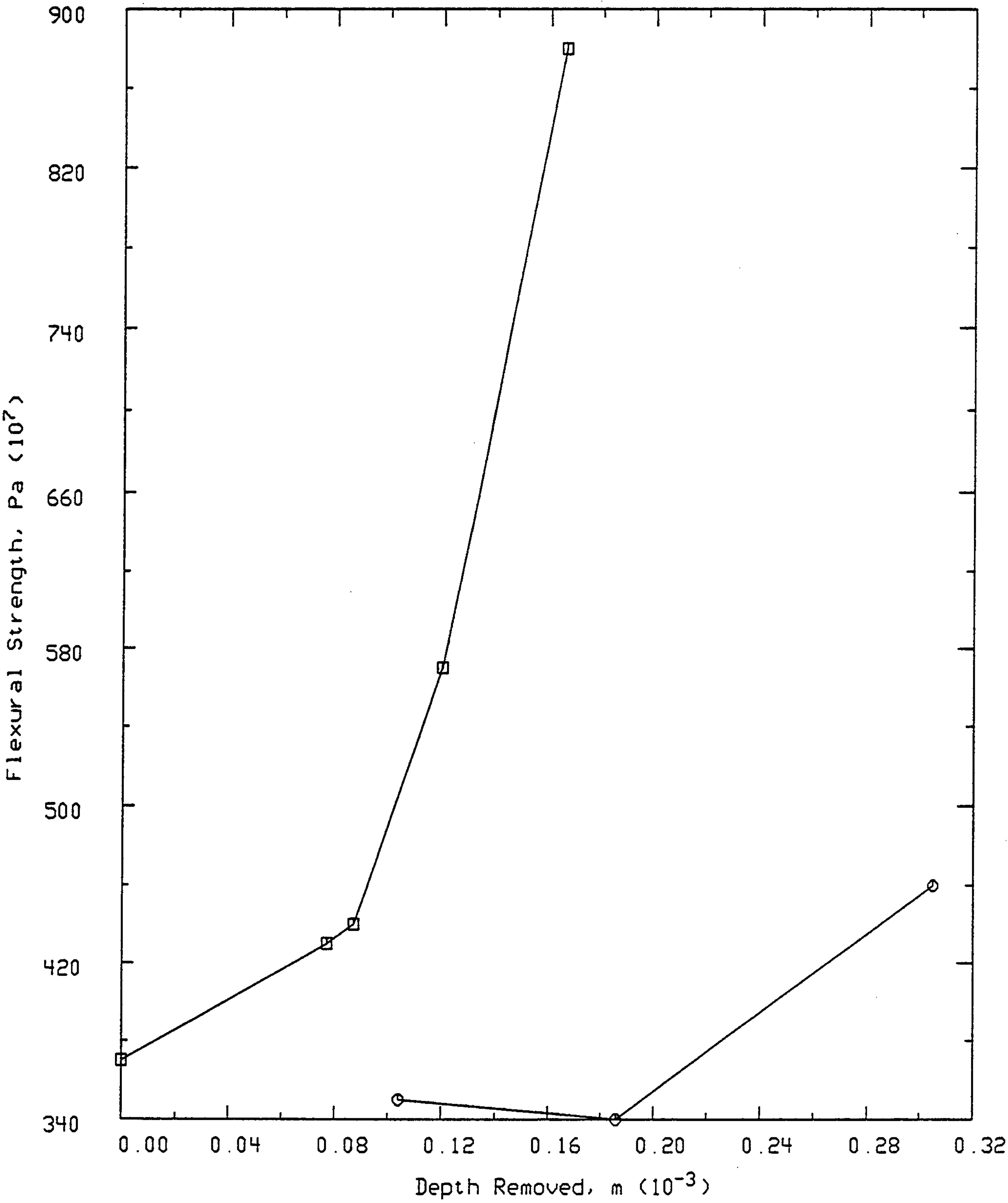

Figure 224 Flexural Strength of Silicon

MATERIAL: Silicon

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 225

****

Additional Preparation/Conditioning

Surface Treatment :

The back surfaces of wafers were either lapped or ground prior to being chemically etched.

Material Microstructure

Single-crystalline silicon

Specimen Identification

Number/Name : Semiconductor grade wafers.

Dimensions (Geometry) :

Thickness	0.28	mm
Width	3.81	mm
Length	3.81	mm

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Ball-Breaker Flexure Test for Wafers

Parameters-Textual :

A square silicon chip was placed on a soft pad (17 sheets from an adhesive paper pad) and loaded by pressure contact from a teflon ball 7.25 mm in diameter. Maximum load was approximately 90 N.

After each test the top sheet of paper was changed and the teflon ball was rotated.

The fracture strength of the tension surface (backface of the wafer) was calculated from elastic plate theory.

Crosshead speed was 0.02 mm/sec.

Measured/Evaluated Properties

X	: Depth Removed	m
Y	: Flexural Strength	Pa
Z1	: Probability of Fracture	fraction
Z2	: Temperature	K

Data Points :

X	Y	Z1	Z2	Remarks:
0.000e+00	2.000e+07	1.000e-01	2.950e+02	Lapped and Etched Silicon
1.300e-05	5.800e+07	1.000e-01	2.950e+02	

2.900e-05	5.100e+07	1.000e-01	2.950e+02	
4.100e-05	1.590e+08	1.000e-01	2.950e+02	
5.200e-05	7.600e+07	1.000e-01	2.950e+02	
6.400e-05	2.210e+08	1.000e-01	2.950e+02	
8.100e-05	1.720e+08	1.000e-01	2.950e+02	
0.000e+00	2.800e+07	5.000e-01	2.950e+02	
1.300e-05	9.500e+07	5.000e-01	2.950e+02	
2.900e-05	8.600e+07	5.000e-01	2.950e+02	
4.100e-05	2.250e+08	5.000e-01	2.950e+02	
5.200e-05	2.120e+08	5.000e-01	2.950e+02	
6.400e-05	3.020e+08	5.000e-01	2.950e+02	
8.100e-05	2.490e+08	5.000e-01	2.950e+02	
0.000e+00	3.000e+07	9.000e-01	2.950e+02	
1.300e-05	1.830e+08	9.000e-01	2.950e+02	
2.900e-05	1.270e+08	9.000e-01	2.950e+02	
4.100e-05	2.590e+08	9.000e-01	2.950e+02	
5.200e-05	2.630e+08	9.000e-01	2.950e+02	
6.400e-05	3.020e+08	9.000e-01	2.950e+02	
8.100e-05	2.490e+08	9.000e-01	2.950e+02	
0.000e+00	3.500e+07	1.000e-01	2.950e+02	Ground and Etched Silicon
1.300e-05	1.580e+08	1.000e-01	2.950e+02	
2.500e-05	1.290e+08	1.000e-01	2.950e+02	
5.600e-05	1.420e+08	1.000e-01	2.950e+02	
1.050e-04	1.750e+08	1.000e-01	2.950e+02	
0.000e+00	4.600e+07	5.000e-01	2.950e+02	
1.300e-05	2.290e+08	5.000e-01	2.950e+02	
2.500e-05	2.270e+08	5.000e-01	2.950e+02	
5.600e-05	2.370e+08	5.000e-01	2.950e+02	
1.050e-04	2.750e+08	5.000e-01	2.950e+02	

Comments on Data

The test limit was 250 - 300 MPa, so that the highest strengths were not determined.
The tabulations were read from Figures 10 and 11 which incurred data point reading errors of +/- 0.4 micron etch depth and +/- 2 MPa fracture strength.
The data indicate that grinding damage can be removed by etching about 15 micron of material, while lapping damage is much more difficult to remove.
Microscopy (SEM) of low-stress fractured surfaces indicated that cracking was initiated at flaws that were either etch pits or scratches, typically 10 micron long and 1 micron wide,

that occurred after etching.

Reference

MEASUREMENT OF SILICON STRENGTH AS AFFECTED BY WAFER BACK PROCESSING.
Hawkins, G. Berg, H. Mahalingam, M.
Lewis, G. Lofgran, L.
INTERNATIONAL RELIABILITY PHYSICS, ANN. PROC.
IEEE, 25TH 1987
216-23, 1987.

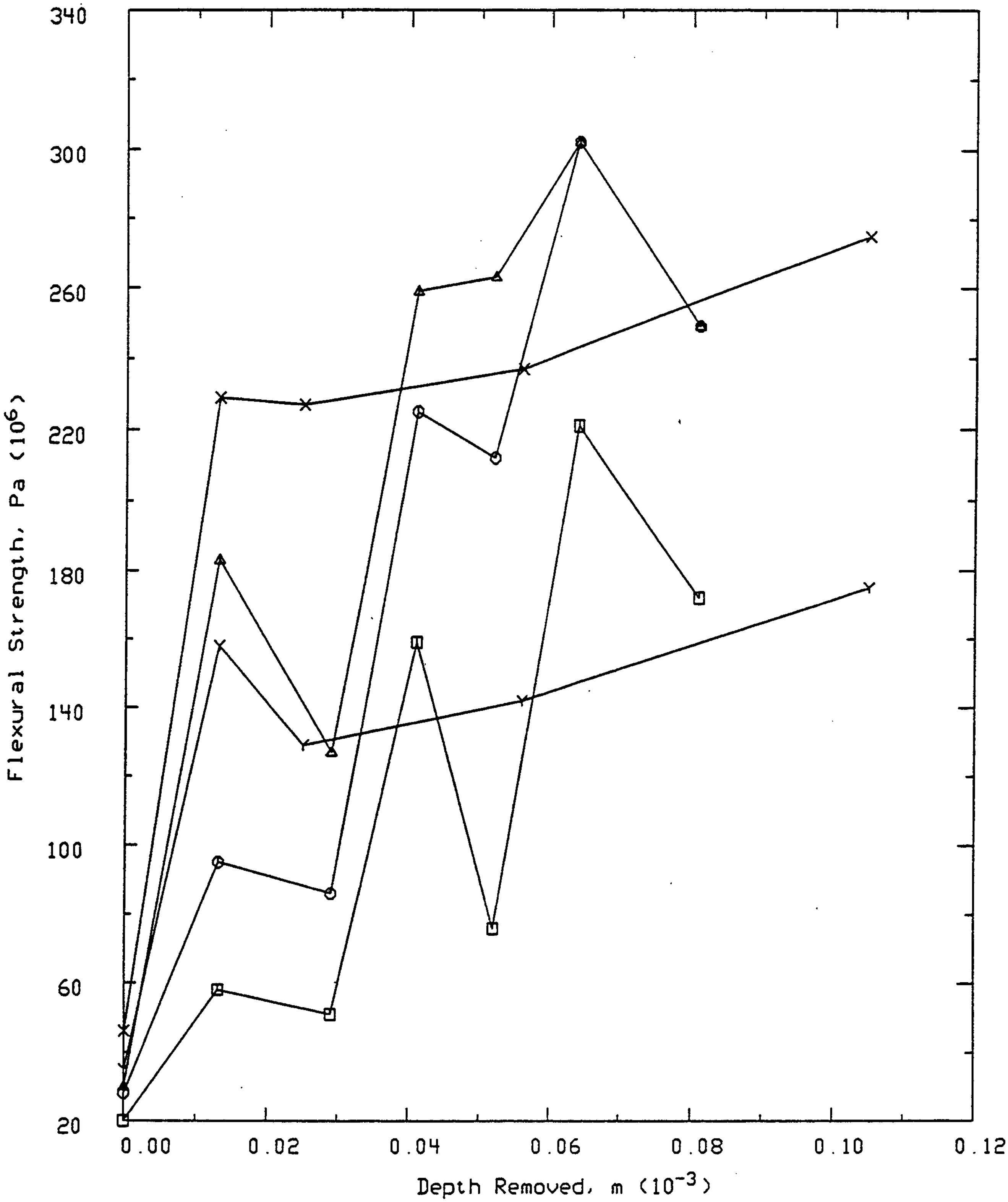

Figure 225 Flexural Strength of Silicon

MATERIAL: Silicon

PROPERTY: Flexural Strength

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 226

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Material Preparation

Crystal Growing Method :
Czochralski

Additional Preparation/Conditioning

Surface Treatment :
Wafers polished on both surfaces to a mirror-finish with silica gel.

Material Microstructure

Single crystalline material.

Panel/Billet/Lot/Batch Number

Lot 1

Specimen Identification

Number/Name : Lot 1 specimens
Orientation With Respect To Material : (100) Plane

Measurement/Evaluation Method

Name/Description :
Ball-and-Ring Flexure Test for Wafers
Parameters-Textual :
Circular aluminum platform had a 5 mm diameter hole with a slightly rounded edge to provide concentric support.
Load was transmitted to wafer by means of a spherical ball (ball diameter either 1.2 or 5.0 mm). Load was increased incrementally to fracture.
Flexure strength was calculated as the stress at fracture in the tensile surface using elastic bending theory.

Measured/Evaluated Properties

X	: Number of Occurrences	
Y	: Flexural Strength	Pa
Z1	: Temperature	K

Data Points :

X	Y	Z1
0.000e+00	0.000e+00	2.950e+02
0.000e+00	5.000e+08	2.950e+02

7.000e+00	1.000e+09	2.950e+02
1.100e+01	1.500e+09	2.950e+02
1.500e+01	2.000e+09	2.950e+02
1.500e+01	2.500e+09	2.950e+02
8.000e+00	3.000e+09	2.950e+02
8.000e+00	3.500e+09	2.950e+02
2.000e+00	4.000e+09	2.950e+02
4.000e+00	4.500e+09	2.950e+02
0.000e+00	5.000e+09	2.950e+02
0.000e+00	6.000e+09	2.950e+02
2.000e+00	6.500e+09	2.950e+02

Comments on Data

Tabulations are a histogram of fracture strength occurrences in intervals of 0.5 GPa lying above the tabulated strength value.

Reference

CRITICAL STRESS IN SILICON BRITTLE FRACTURE, AND EFFECT OF ION IMPLANTATION AND OTHER SURFACE TREATMENTS.
Hu, S. M.
J. APPL. PHYS.
53 (5), 3576-80, 1982.

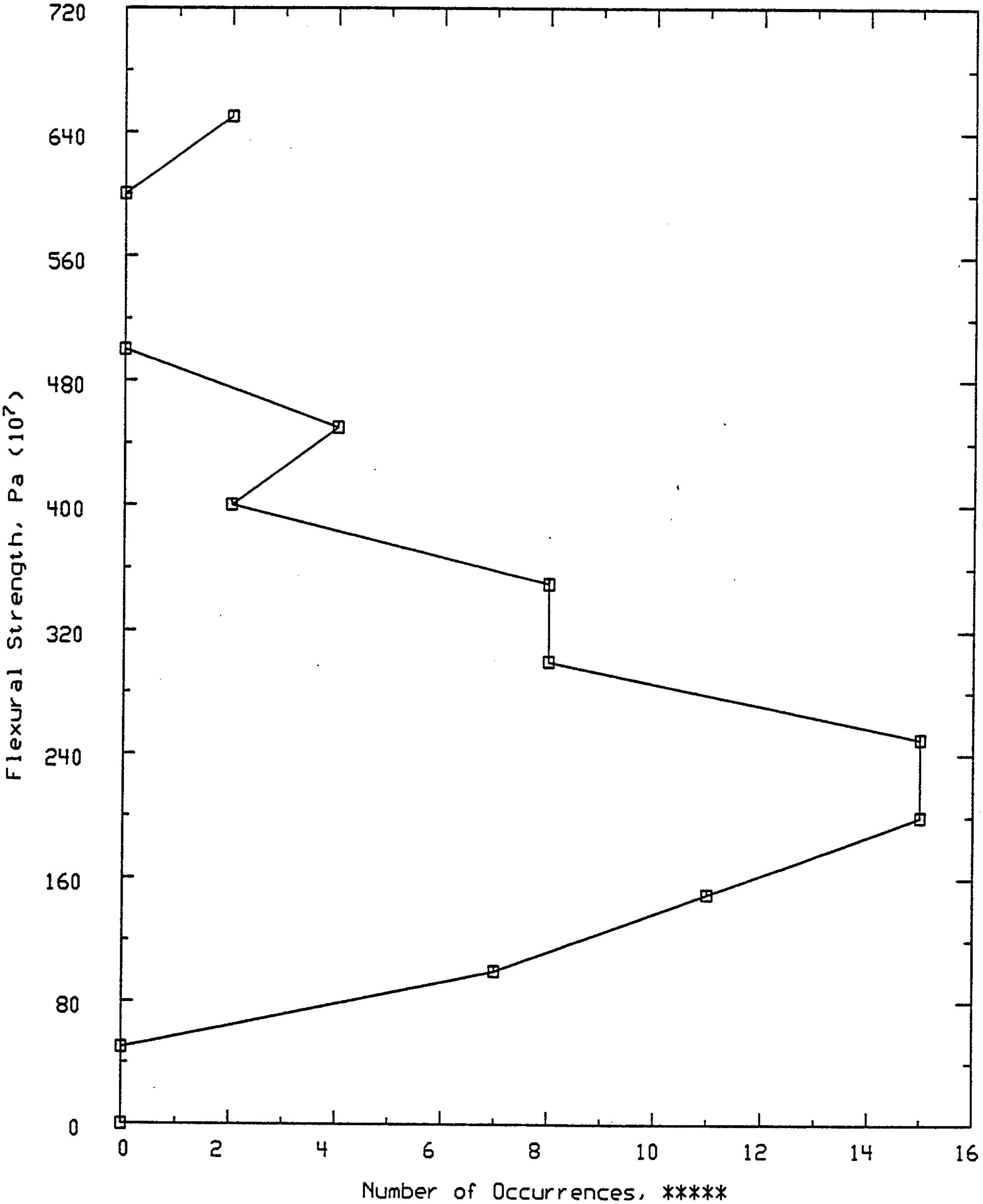

Figure 226 Flexural Strength of Silicon

MATERIAL: Silicon: B doped	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Flexural Strength, Yield	DATA SET 227

****

Vendor/Producer/Fabricator

Mitsubishi Electric Corp.

Material Preparation

Crystal Growing Method :
Czochralski-grown crystals

Specimen Identification

Dimensions (Geometry) :

Length	32.	mm
Width	5.0	mm
Thickness	0.53	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	15-25	Ω cm
Temperature	298.	K

Other Properties-Numerical :

Oxygen Concentration	11.5e17	cm^{-3}
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :
Four-Point Bend Test
Parameters-Textual :
Four-point loading device made of quartz and the distances between inner and outer knife-edges are 8 and 24 mm, respectively.
The device was attached to an Instron machine.
Parameters-Codified :
Strain Rate : 1.5e-06 s[-1]

Measured/Evaluated Properties

X : Temperature	K
Y : Flexural Strength, Yield	Pa

Data Points :

X	Y
9.800e+02	8.840e+07

1.028e+03	6.400e+07
1.076e+03	4.370e+07

Comments on Data

Data was digitized from figure 2
yield strength of the as-received CZ-wafers decreases
monotonously with T.

Reference

MECHANICAL PROPERTIES OF HEAT-TREATED CZ-SILICON WAFERS FROM BRITTLE TO DUCTILE TEMPERATURE RANGE.
Yasutake, K. Murakami, J. Umeno, M.
Kawabe, H.
JPN. J. APPL. PHYS., PART 2
21 (5), 288-90, 1982.

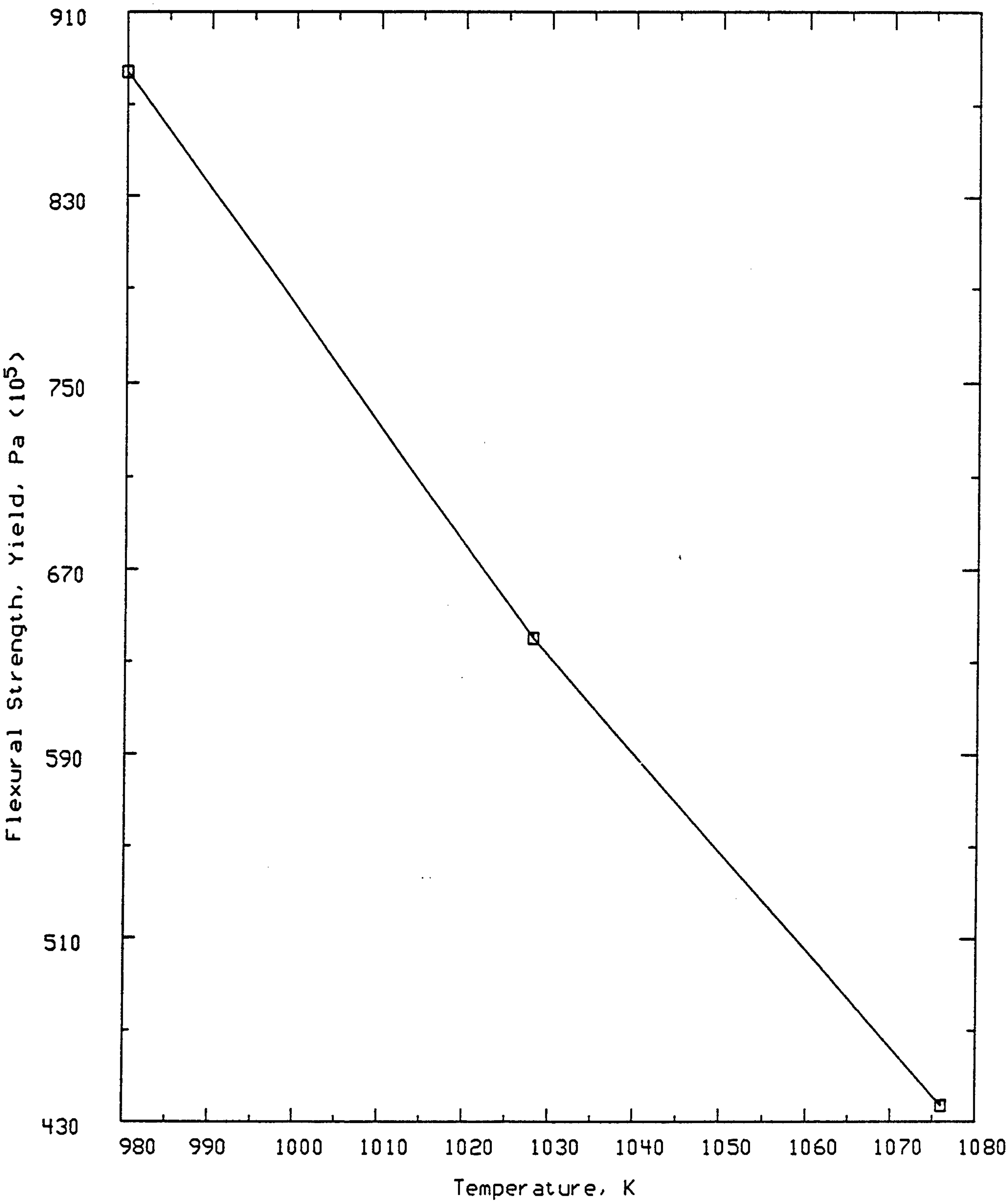

Figure 227 Flexural Strength, Yield of Silicon: B doped

MATERIAL: Silicon: B doped	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Flexural Strength, Yield	DATA SET 228

****

Vendor/Producer/Fabricator

Mitsubishi Electric Corp.

Material Preparation

Crystal Growing Method :

Floating-zone-grown crystals.

Specimen Identification

Dimensions (Geometry) :

Length	32.	mm
Width	5.0	mm
Thickness	0.53	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	15-25	Ω cm
Temperature	298.	K

Measurement/Evaluation Method

Name/Description :

Four-Point Bend Test

Parameters-Textual :

Four-point loading device made of quartz and the distances between inner and outer knife-edges are 8 and 24 mm, respectively.

The device was attached to an Instron machine.

Parameters-Codified :

Strain Rate : 1.5e-06 s[-1]

Measured/Evaluated Properties

X : Temperature	K
Y : Flexural Strength, Yield	Pa

Data Points :

X	Y
9.280e+02	1.593e+08
9.800e+02	9.380e+07
1.028e+03	6.040e+07
1.076e+03	5.370e+07

Comments on Data

Data was digitized from figure 2
Yield strength of the as-received FZ-wafers decreases monotonously with T.

Reference

MECHANICAL PROPERTIES OF HEAT-TREATED CZ-SILICON WAFERS FROM BRITTLE TO DUCTILE TEMPERATURE RANGE.
Yasutake, K. Murakami, J. Umeno, M.
Kawabe, H.
JPN. J. APPL. PHYS., PART 2
21 (5), 288-90, 1982.

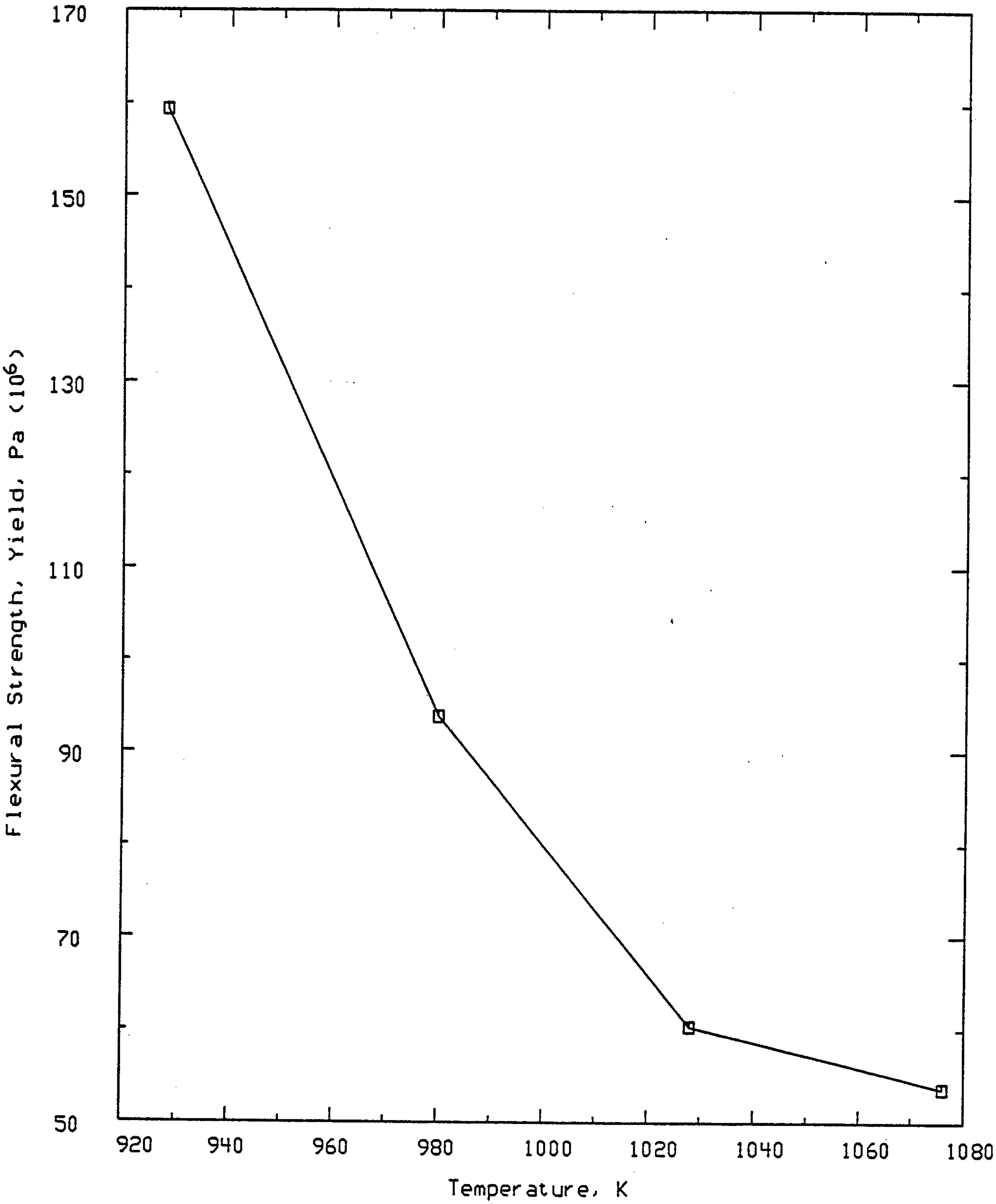

Figure 228 Flexural Strength, Yield of Silicon: B doped

MATERIAL: Silicon: B doped	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Flexural Strength, Yield	DATA SET 229

****

Vendor/Producer/Fabricator

Mitsubishi Electric Corp.

Material Preparation

Crystal Growing Method :
Czochralski-grown crystals
Descriptors-Textual :
Chemically ploished and then annealed at 1073 K for 100 hrs.

Specimen Identification

Dimensions (Geometry) :

Length	32.	mm
Width	5.0	mm
Thickness	0.53	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	15-25	Ω cm
Temperature	298.	K

Other Properties-Textual :
Etch pit density: approx. 8.0e09 cm[-3]
SiO(2) precipitate size: approx. 4200 Angstroms.

Measurement/Evaluation Method

Name/Description :
Four-Point Bend Test
Parameters-Textual :
Four-point loading device made of quartz and the distances between inner and outer knife-edges are 8 and 24 mm, respectively.
The device was attached to an Instron machine.
Parameters-Codified :
Strain Rate : 1.5e-06 s[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Flexural Strength, Yield	Pa

Data Points :

X	Y
7.960e+02	3.845e+08
8.120e+02	3.627e+08
8.200e+02	3.130e+08
8.280e+02	2.546e+08
8.600e+02	2.073e+08
8.760e+02	1.638e+08
9.280e+02	1.023e+08
9.760e+02	7.190e+07
1.028e+03	4.490e+07
1.076e+03	3.350e+07

Comments on Data

Data was digitized from figure 2
Yield strength of wafers at 973 K are remarkably lowered by heat treatment. Platelike SiO(2) precipitates of about 10.e10cm[-3] are observed by TEM and etch-pit method, but no punched-out dislocation loops exist. Annealed CZ wafers become ductile at T above 793 K.

Reference

MECHANICAL PROPERTIES OF HEAT-TREATED CZ-SILICON WAFERS FROM BRITTLE TO DUCTILE TEMPERATURE RANGE.
Yasutake, K. Murakami, J. Umeno, M.
Kawabe, H.
JPN. J. APPL. PHYS., PART 2
21 (5), 288-90, 1982.

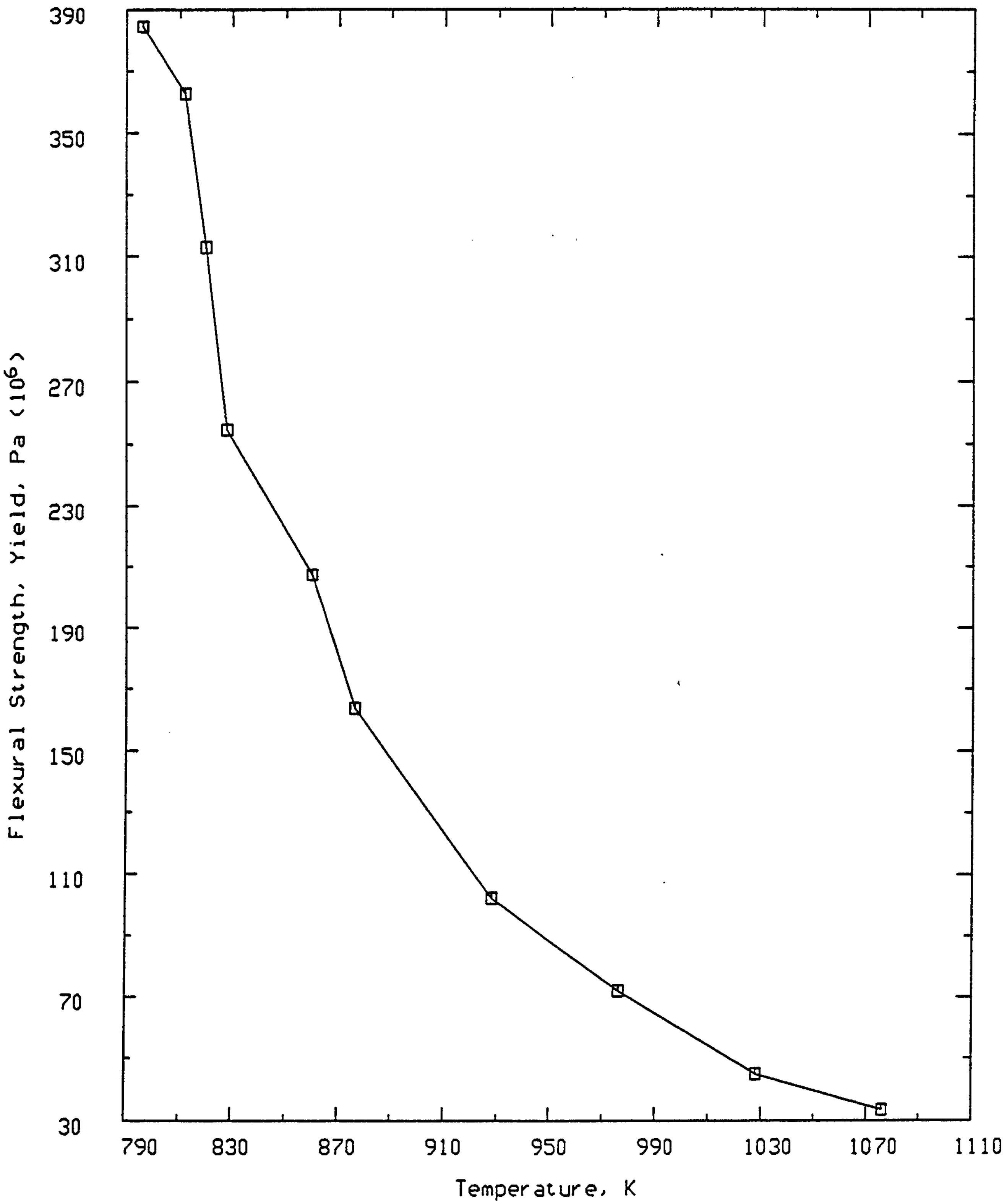

Figure 229 Flexural Strength, Yield of Silicon: B doped

MATERIAL:	Silicon: B doped	HTMIAC/CINDAS 1994 PURDUE UNIVERSITY
PROPERTY:	Fracture Toughness, Plane-Strain K(Ic)	DATA SET 230

****

Material Preparation

Crystal Growing Method :

Floating-Zone (FZ)

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation

Descriptors-Textual :

Specimens were chemically polished to remove surface damage prior to indenting (CH(3)COOH:HNO(3):HF (1:10:1))

Precursor crack produced by Knoop diamond indentor at center of tensile surface and in (110) plane such that crack was oriented perpendicular to tensile stress. Indentation load varied from 50 to 500g.

Pre-cracked specimens were annealed in a quartz furnace at 700 C under vacuum of 2.6e-04 Pa.

Material Microstructure

Dislocation-free 100 mm diameter (001) wafers

Interstitial oxygen (infra-red absorption): 1.0e+16 cm[-3] in FZ crystals.

Substitutional carbon content was below instrumental detection limit

Specimen Identification

Dimensions (Geometry) :

Length	32	mm
Width	4	mm
Thickness	0.5	mm

Orientation With Respect To Material : [110] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	17-23	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :

Four-Point Bend Test on Pre-Cracked Specimens

Instron machine (Model TTCM-L) fixture has stainless steel sample supports separated by 25mm (outer) and 10mm (inner).

The fracture stress on the outermost (tensile) surface was computed by simple elastic beam theory.

Parameters-Codified :
Cross-Head Speed : 0.02mm min[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Fracture Toughness, Plane-Strain K(Ic)	Pa $m^{1/2}$

Data Points :

X	Y	Remarks:
2.950e+02	9.100e+05	S.D. = 0.09 MPa m[1/2], (110) Crack Plane

Comments on Data

Approximately 30 specimens having varying pre-cracked lengths were measured and averaged together.
SEM profiles of the fracture surface indicate a semi-elliptical precursor crack and no stable crack growth.
Vacuum annealing evidently releases residual stresses around the precursor crack which would otherwise act as a driving force for crack extension.
Alternatively, annealing in air or oxygen was found to heal precursor cracks and increase fracture strength.
No appreciable difference between CZ and FZ material was observed.

Reference

CRACK HEALING AND FRACTURE STRENGTH OF SILICON CRYSTALS.
Yasutake, K. Iwata, M. Yoshii, K.
Umeno, M. Kawabe, H.
J. MATER. SCI.
21 (6), 2185-92, 1986.

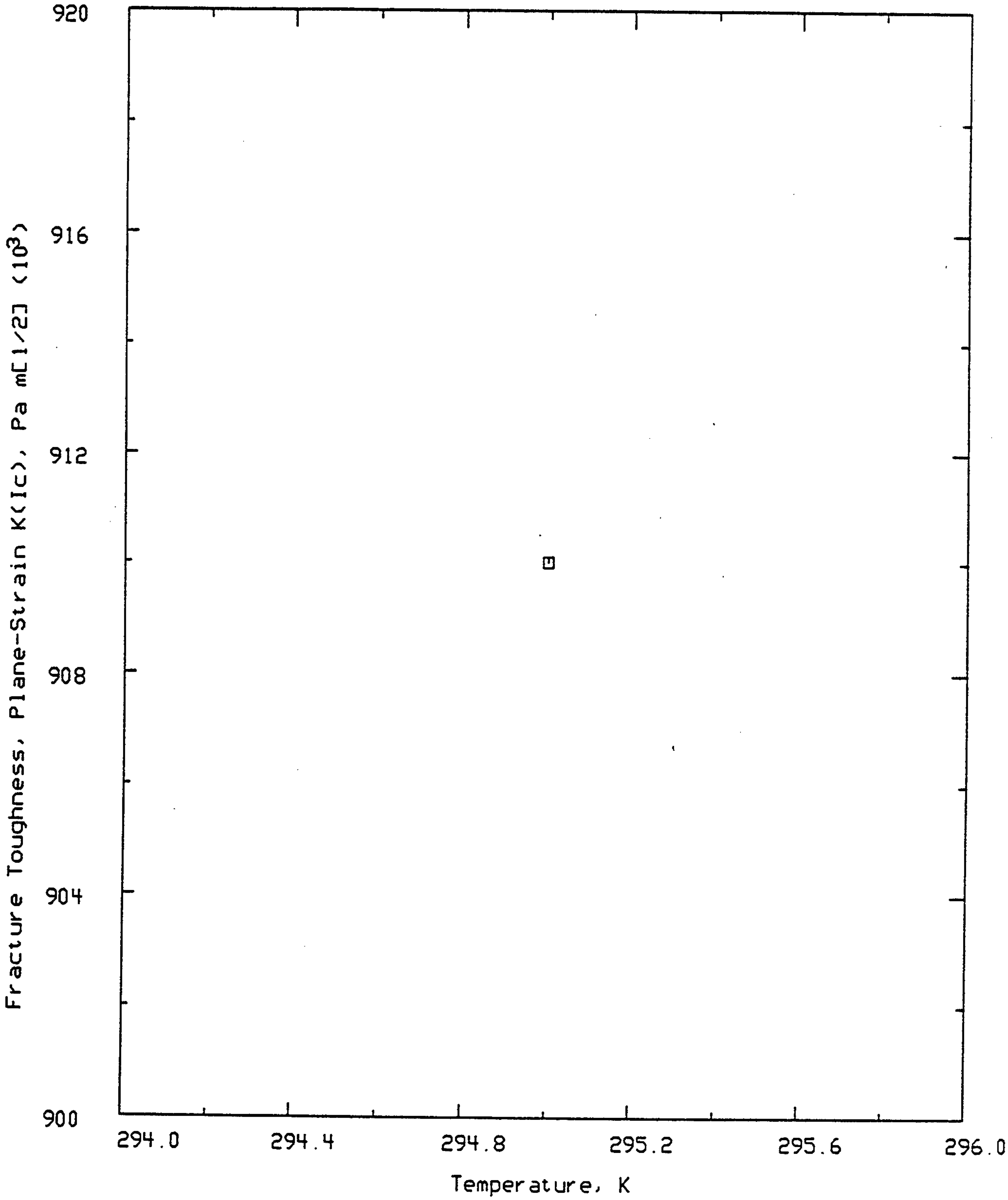

Figure 230 Fracture Toughness, Plane-Strain K(Ic) of Silicon: B dopec

MATERIAL: Silicon: B doped

PROPERTY: Fracture Toughness, Plane-Strain K(Ic)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 231

****

Material Preparation

Crystal Growing Method :
Floating-Zone (FZ)

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :
Specimens were chemically polished to remove surface damage prior to indenting (CH(3)COOH:HNO(3):HF (1:10:1))
Precursor crack produced by Knoop diamond indentor at center of tensile surface and in (110) plane such that crack was oriented perpendicular to tensile stress. Indentation load varied from 50 to 500g.
Pre-cracked specimens were annealed in a quartz furnace at 700 C under vacuum of 2.6e-04 Pa.

Material Microstructure

Dislocation-free 100 mm diameter (001) wafers
Interstitial oxygen (infra-red absorption): 1.0e+16 cm[-3] in FZ crystals.
Substitutional carbon content was below instrumental detection limit

Specimen Identification

Dimensions (Geometry) :

Length	32	mm
Width	4	mm
Thickness	0.5	mm

Orientation With Respect To Material : [100] Direction

Additional Properties

Electrical Properties :

Electrical Resistivity	17-23	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :
Four-Point Bend Test on Pre-Cracked Specimens
Instron machine (Model TTCM-L) fixture has stainless steel sample supports separated by 25mm (outer) and 10mm (inner).
The fracture stress on the outermost (tensile) surface was computed by simple elastic beam theory.

Parameters-Codified :
Cross-Head Speed : 0.02mm min[-1]

Measured/Evaluated Properties

X	: Temperature	K
Y	: Fracture Toughness, Plane-Strain K(Ic)	Pa $m^{1/2}$

Data Points :

X	Y	Remarks:
2.950e+02	9.500e+05	S.D. = 0.10 MPa m[1/2], (100) Crack Plane

Comments on Data

Approximately 30 specimens having varying pre-cracked lengths were measured and averaged together.
SEM profiles of the fracture surface indicate a semi-elliptical precursor crack and no stable crack growth.
Vacuum annealing evidently releases residual stresses around the precursor crack which would otherwise act as a driving force for crack extension.
Alternatively, annealing in air or oxygen was found to heal precursor cracks and increase fracture strength.
No appreciable difference between CZ and FZ material was observed.

Reference

CRACK HEALING AND FRACTURE STRENGTH OF SILICON CRYSTALS.
Yasutake, K. Iwata, M. Yoshii, K.
Umeno, M. Kawabe, H.
J. MATER. SCI.
21 (6), 2185-92, 1986.

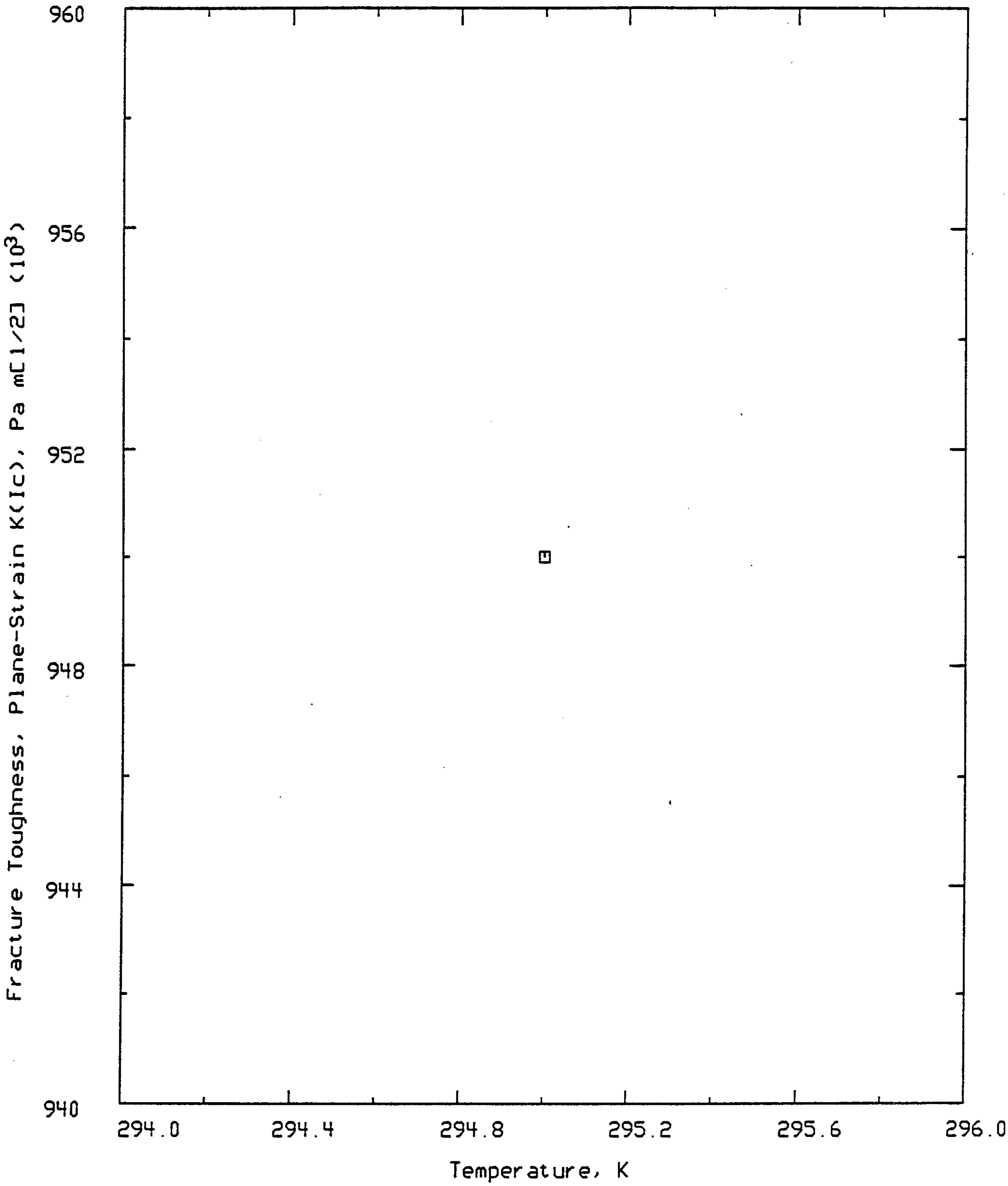

Figure 231 Fracture Toughness, Plane-Strain K(Ic) of Silicon: B dopec

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Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :

Precursor cracks at the notch root of double cantilever beam specimens were propagated from a scratch by slowly forcing a wedge into the open notch while simultaneously applying a compressive stress across the crack plane. Precursor crack region was found to be free of dislocations by x-ray topography.

Surface Treatment :

Superficial machining abrasions were removed by chemical polishing

Material Microstructure

Single-crystalline material, ingot growth along <111>, p-type

Specimen Identification

Number/Name : Precracked Double-Cantilever Beam Specimen
Orientation With Respect To Material : [110] Direction
Additional Identifiers :

Double cantilever specimen was shaped like a truncated triangle.
Dimensions: base of triangle = 18.0 mm
height of triangle = 30.0 mm
width of truncated top = 5.3 mm
length of notch from top = 10.0 mm
holes for loading fixture had diameters of 1.0 mm, separation of 3.0 mm, and positions 1.5 mm from top

Additional Properties

Electrical Properties :

Electrical Resistivity	43	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :

Double Cantilever Beam with Pre-Cracked Specimen
Loading applied in a crack-opening orientation and with displacement speed of 5 to 500 micron/min.
Carefully taken load-deflection curve data indicated repeated (up to 8 in number) crack-initiation, propagation, and arrest features. Careful examination by interference microscopy allowed

precise crack-length measurement to be made.
Data were analysed by applying existing critical stress intensity theory for this type of specimen.

Measured/Evaluated Properties

X : Temperature	K
Y : Fracture Toughness, Plane-Strain K(Ic)	Pa $m^{1/2}$
Z1 : Cross-Head Speed	m s^{-1}

Data Points :

X	Y	Z1	Remarks:
7.715e+01	9.400e+05	8.333e-08	(111) Crack Planes
2.951e+02	9.370e+05	8.333e-08	Stand. Dev. = 0.052 MPa m[1/2]
9.782e+02	1.000e+06	8.333e-08	Approx. extrapolated
1.008e+03	1.000e+06	1.667e-07	
1.076e+03	1.000e+06	8.333e-07	
1.128e+03	1.000e+06	1.667e-06	
1.210e+03	1.000e+06	8.333e-06	

Comments on Data

Ductile-to-brittle transition is between 1074 and 1078 K for 50 micron/min cross-head speed.
The extrapolations were made from a few data points just below the ductile-to-brittle transition for each cross-head speed.
The fracture toughness was found to be essentially temperature and rate independent.

Reference

THE BRITTLE-TO-DUCTILE TRANSITION IN PRE-CLEAVED SILICON SINGLE CRYSTALS.
St. John, C.
PHILOS. MAG.
32, 1193-212, 1975.

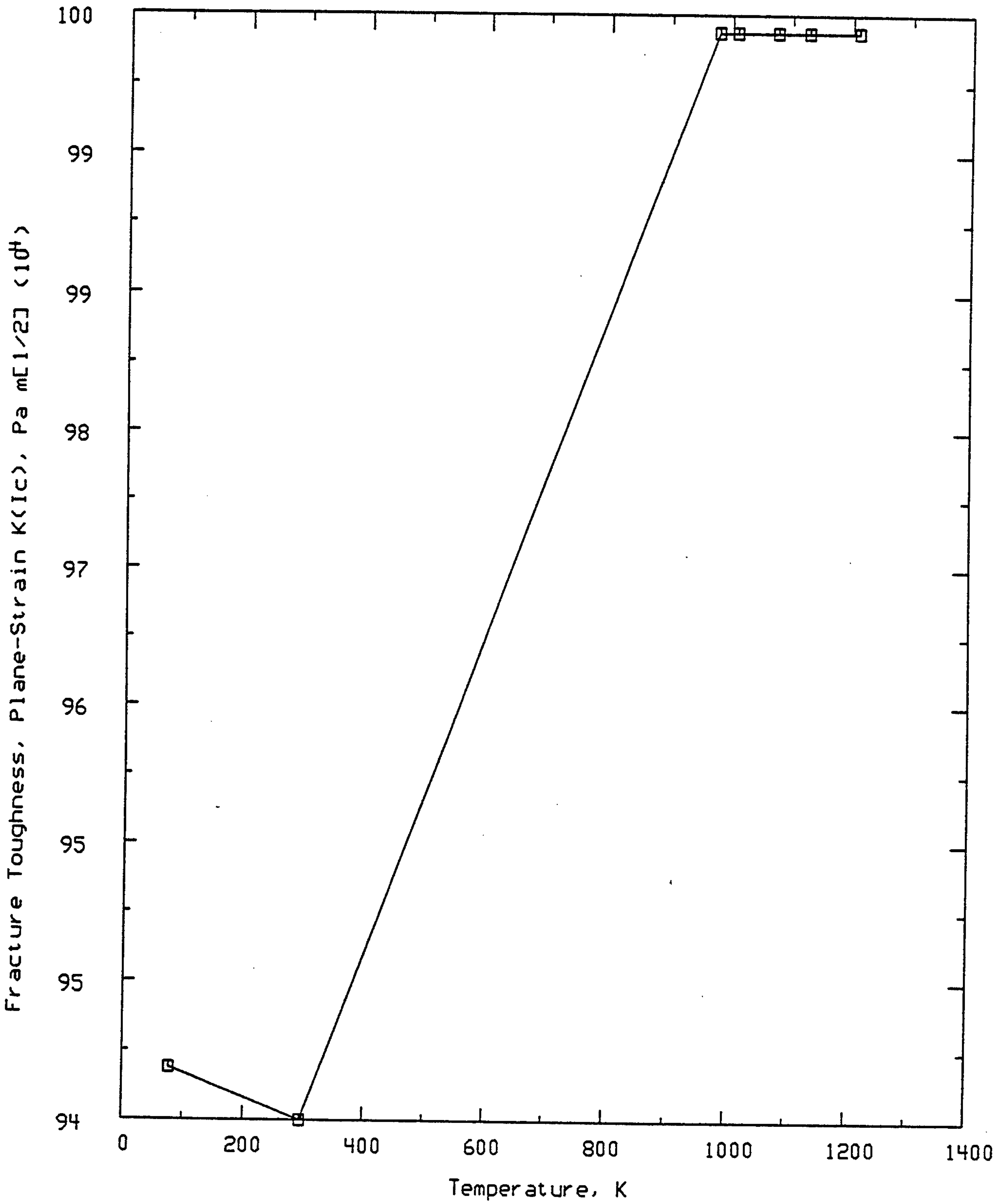

Figure 232 Fracture Toughness, Plane-Strain K(Ic) of Silicon: B dopec

MATERIAL: Silicon | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Fracture Toughness, Plane-Strain K(Ic) | DATA SET 233

****

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation

Descriptors-Textual :

Indentation was produced by a Vickers pyramid indentor at a load of 30N. Indent occured at the center of a face, with radial cracks aligned parallel to the edges.

Material Microstructure

Single crystal slices having (111) surfaces

Specimen Identification

Dimensions (Geometry) :

Thickness	1	mm

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Indentation Fracture Method For Fracture Toughness
Indentation site was at center of tension face.
Existing theory of radial crack growth due to indentation stress field was applied to the crack system analysis.
Crack length used for each indentation was averaged over the four radial traces produced by the pyramid indentor.
The computation for fracture toughness required elastic modulus (E) and hardness (Vickers used here) data as input. Literature values used were E=168GPa and H=9.0GPa.

Experimental Conditioning/Material Degradation

Conditioning/Degradation/Environment : Air Environment

Measured/Evaluated Properties

X	: Temperature	K
Y	: Fracture Toughness, Plane-Strain K(Ic)	Pa $m^{1/2}$

Data Points :

X	Y	Remarks:
2.950e+02	7.600e+05	Standard Deviation = 0.19 MPa m[1/2]

Comments on Data

Crack surfaces were perpendicular to specimen surface (111).

Reference

MECHANICS OF STRENGTH-DEGRADING CONTACT FLAWS IN SILICON.
Lawn, B. R. Marshall, D. B. Chantikul, P.
J. MATER. SCI.
16 (7), 1769-75, 1981.

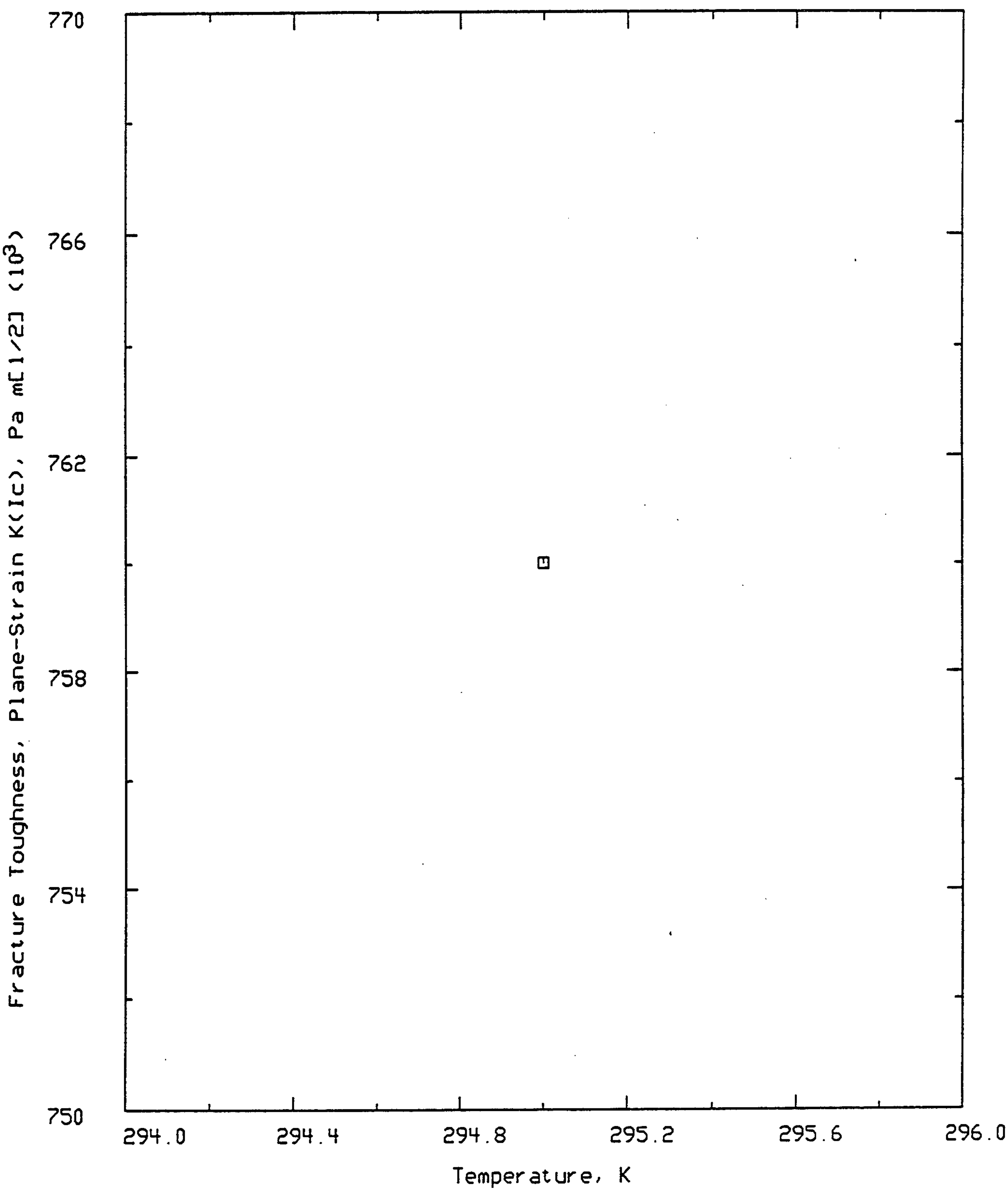

Figure 233 Fracture Toughness, Plane-Strain K(Ic) of Silicon

MATERIAL: Silicon

PROPERTY: Fracture Toughness, Plane-Strain K(Ic)

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PURDUE UNIVERSITY
DATA SET 234

****

Material Microstructure

Single Crystal with dislocation density less than 1.0e+03 cm[-2]

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Microindentation Followed by Loading to Fracture

Measured/Evaluated Properties

X : Temperature — K

Y : Fracture Toughness, Plane-Strain K(Ic) — Pa $m^{1/2}$

Data Points :

X	Y
2.930e+02	1.320e+06
4.800e+02	1.300e+06
6.730e+02	9.200e+05
8.730e+02	8.600e+05
9.730e+02	8.800e+05

Comments on Data

Elevated temperature tabulations were read from Figure 2.

Reference

INFLUENCE OF TEMPERATURE ON THE FAILURE OF BRITTLE MATERIALS IN CONCENTRATED LOADING.
Grigor'ev, O. N. Trefilov, V. I.
Shatokhin, A. M.
POROSHK. METALL.
22 (12), 75-82, 1983.
(FOR ENGLISH TRANSLATION SEE SOV. POWDER METALL. MET. CERAM., 22 (12), 1028-33, 1983)

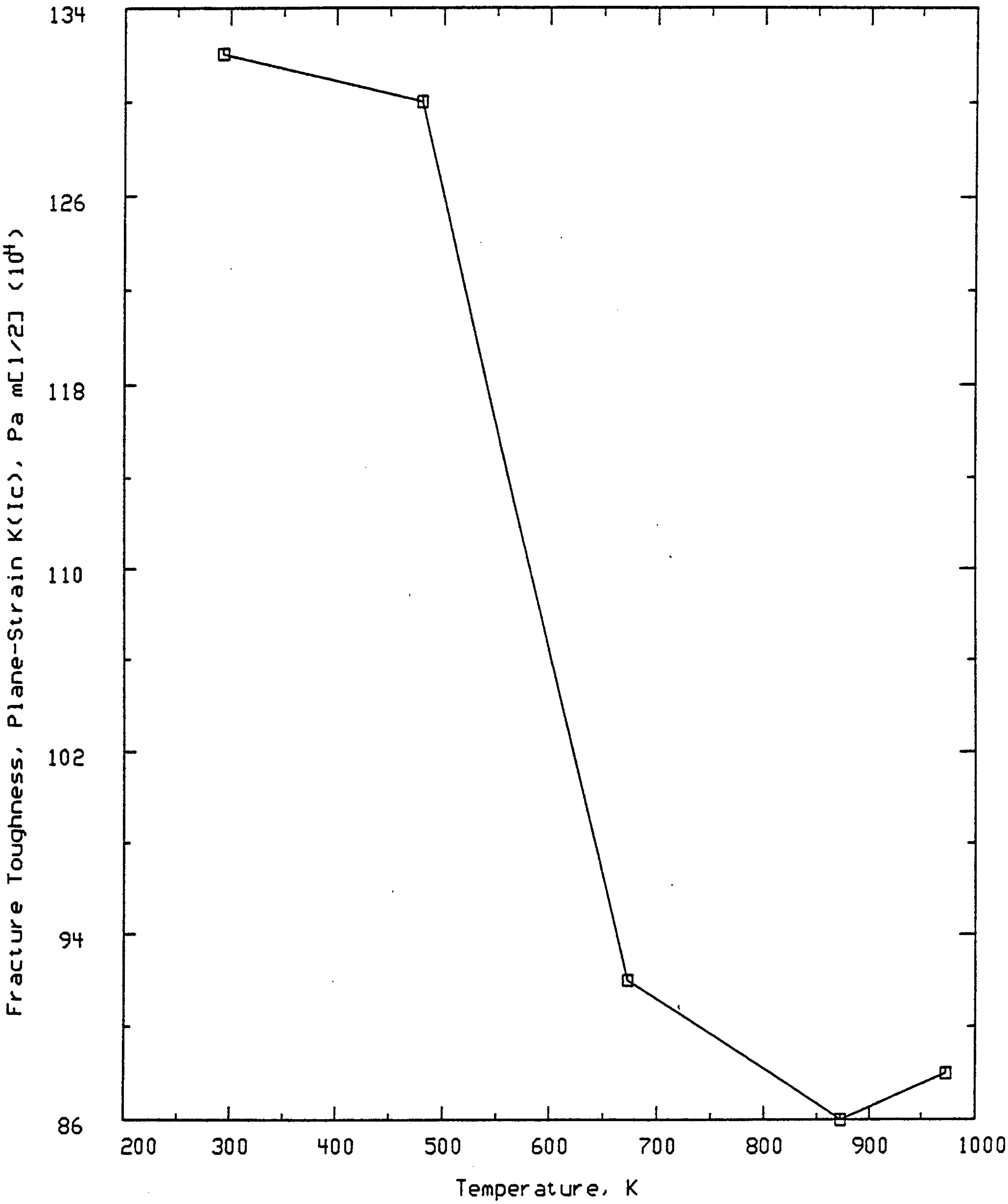

Figure 234 Fracture Toughness, Plane-Strain K(Ic) of Silicon

MATERIAL: Silicon

PROPERTY: Fracture Toughness, Plane-Strain K(Ic)

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PURDUE UNIVERSITY
DATA SET 235

****

Vendor/Producer/Fabricator

Texas Instruments

Material Product Form :

Prepolished semiconductor grade single crystal.

Specimen Identification

Number/Name : Su101
Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Indentation Fracture Method For Fracture Toughness
Under ambient conditions, the load dependence of both radial and diagonal cracks was measured. Crack lengths were measured along the surface around the indentations.
The expected crack planes include (110) planes normal to the (111) surface. Their traces perpendicular to the sample surface lie along <121>.
Existing theory of radial crack growth due to indentation stress fields was applied. Literature values of tensile modulus and (Vickers) hardness were used to calculate fracture toughness.

Measured/Evaluated Properties

X : Temperature — K
Y : Fracture Toughness, Plane-Strain K(Ic) — Pa $m^{1/2}$

Data Points :

X	Y	Remarks:
2.950e+02	7.440e+05	2N Indentor Load
2.950e+02	8.860e+05	5N Indentor Load

Comments on Data

Five samples were measured for each load.

Reference

CHANGING THE SURFACE MECHANICAL PROPERTIES OF SILICON AND ALPHA-ALUMINUM OXIDE BY ION IMPLANTATION.
Burnett, P. J. Page, T. F.
J. MATER. SCI.

19, 3524-45, 1984.

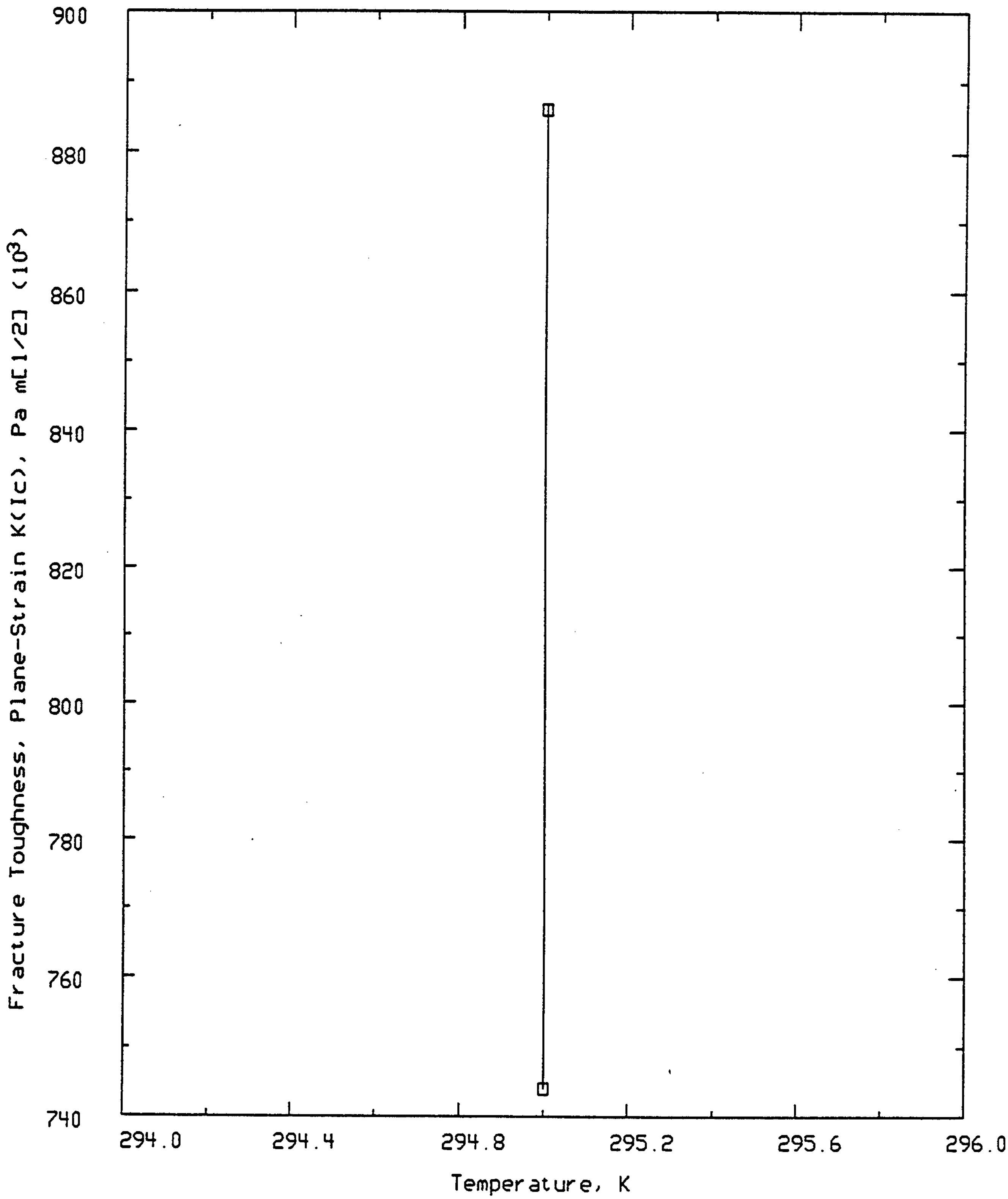

Figure 235 Fracture Toughness, Plane-Strain K(Ic) of Silicon

MATERIAL: Silicon

PROPERTY: Fracture Toughness, Plane-Strain K(Ic)

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 236

****

Material Preparation

Crystal Growing Method :

Czochralski grown, 4 cm diameter ingot

Additional Preparation/Conditioning

Surface Treatment :

One surface was polished to mirror-like finish with 0.05 micron alumina (Linde B) as the final abrasive.

Material Microstructure

Dislocation-free material

Specimen Identification

Orientation With Respect To Material : (111) Plane

Measurement/Evaluation Method

Name/Description :

Microindentation and Crack-System Analysis
Microindentation achieved in ambient air with a Vickers diamond indentor under loads of 2 to 5 N.

Parameters-Textual :

Crack pattern formed was two virtually orthogonal semicircular cracks along (110) and (112) planes, perpendicular to the (111) specimen surface.
Characteristic dimensions of surface cracks were measured with a tracking microscope.
The theoretical model applied toward the analysis is well established.

Measured/Evaluated Properties

X : Temperature — K
Y : Fracture Toughness, Plane-Strain K(Ic) — Pa $m^{1/2}$

Data Points :

X	Y	Remarks:
2.950e+02	1.000e+06	Standard Deviation = 0.08 MPa m[1/2]

Comments on Data

Number of specimens tested was at least 20.
Crack surfaces were (110) and (112) planes.

No evidence of environmental influences on crack resistance was observed.

Reference

MICROINDENTATION FOR FRACTURE AND STRESS-CORROSION CRACKING STUDIES IN SINGLE-CRYSTAL SILICON.
Wong, B. Holbrook, R. J.
J. ELECTROCHEM. SOC.
134 (9), 2254-6, 1987.

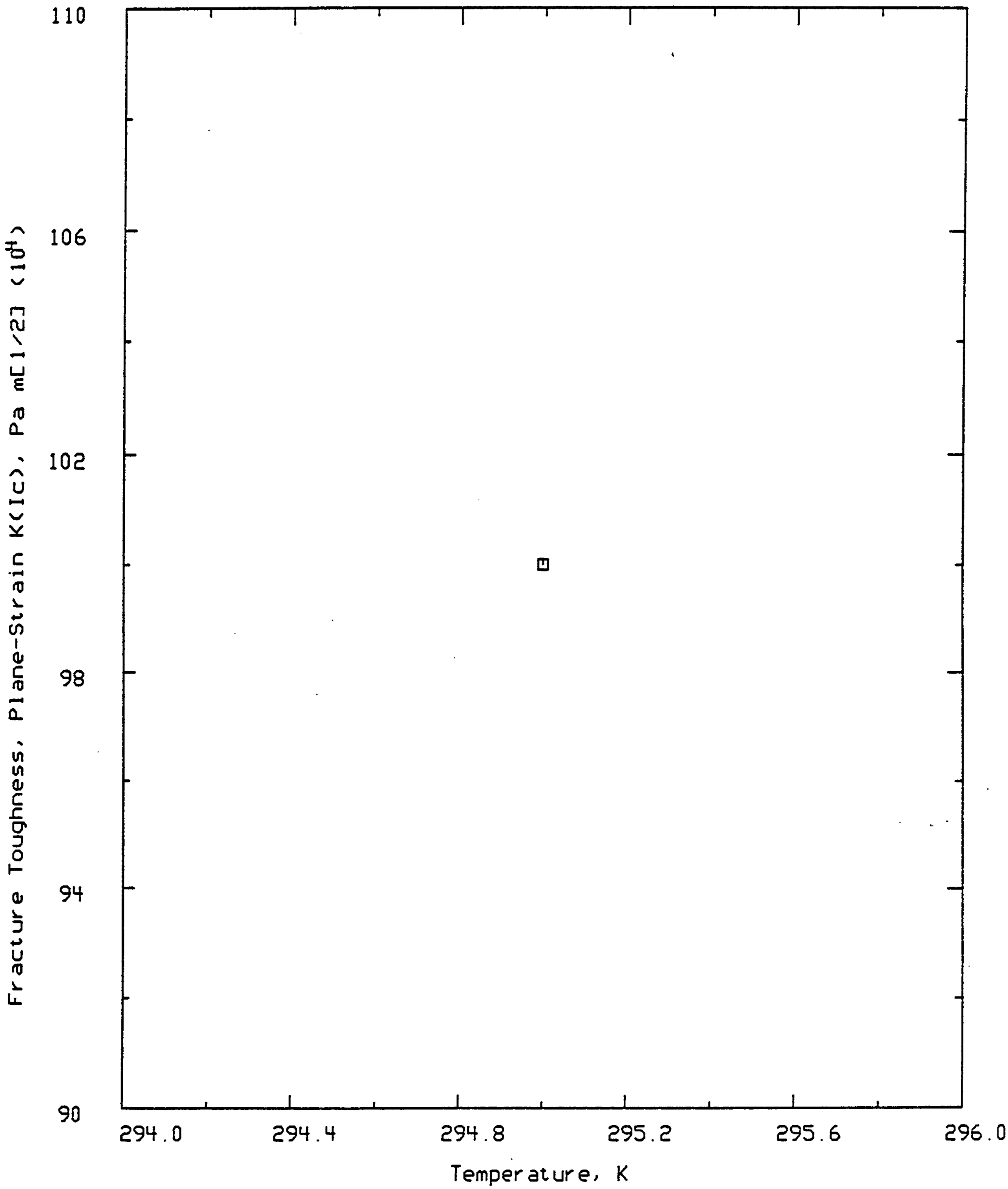

Figure 236 Fracture Toughness, Plane-Strain K(Ic) of Silicon

MATERIAL: Silicon

PROPERTY: Fracture Toughness, Plane-Strain K(Ic)

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PURDUE UNIVERSITY
DATA SET 237

****

Material Preparation

Crystal Growing Method :
Directional solidification casting

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :
Precursor cracks produced by Vickers indentor under 20N load directed into the tensile surface with indentor axes parallel to sample edges.
Flaw lengths were measured with SEM on fractured surfaces.

Material Microstructure

Grain Sizes: 0.3 to 3 mm perpendicular to growth direction
1 to 10 mm parallel to growth direction

Specimen Identification

Number/Name : Directionally Cast Polycrystalline Silicon
Dimensions (Geometry) :

Length	50.8	mm
Width	2.74	mm
Thickness	6.04	mm

Orientation With Respect To Material : Transverse Direction in T-L Plane

Measurement/Evaluation Method

Name/Description :
Four-Point Flexural Test on Pre-Indented Specimens
Major span distance was 40 mm and minor span was 19 mm

Measured/Evaluated Properties

X	: Temperature	K
Y	: Fracture Toughness, Plane-Strain K(Ic)	Pa $m^{1/2}$
Z1	: Flexural Strength	Pa

Data Points :

X	Y	Z1	Remarks:
2.950e+02	8.200e+05	6.560e+07	
2.950e+02	9.700e+05	8.620e+07	
2.950e+02	9.600e+05	6.600e+07	
2.950e+02	7.400e+05	7.140e+07	

2.950e+02	8.500e+05	7.950e+07	
2.950e+02	8.700e+05		Average: Stand. Dev. = 11.2 %

Comments on Data

Crack propagation is transverse to grains for this orientation. Since flaw size (typically 0.2 mm) is smaller than grain size these fracture toughness results are not much different from single-crystalline silicon data.

Reference

FRACTURE OF DIRECTIONALLY SOLIDIFIED MULTICRYSTALLINE SILICON.
Chen, C. P. Leipold, M. H., Jr.
Helmreich, D.
J. AM. CERAM. SOC.
65, C-49, 1982.

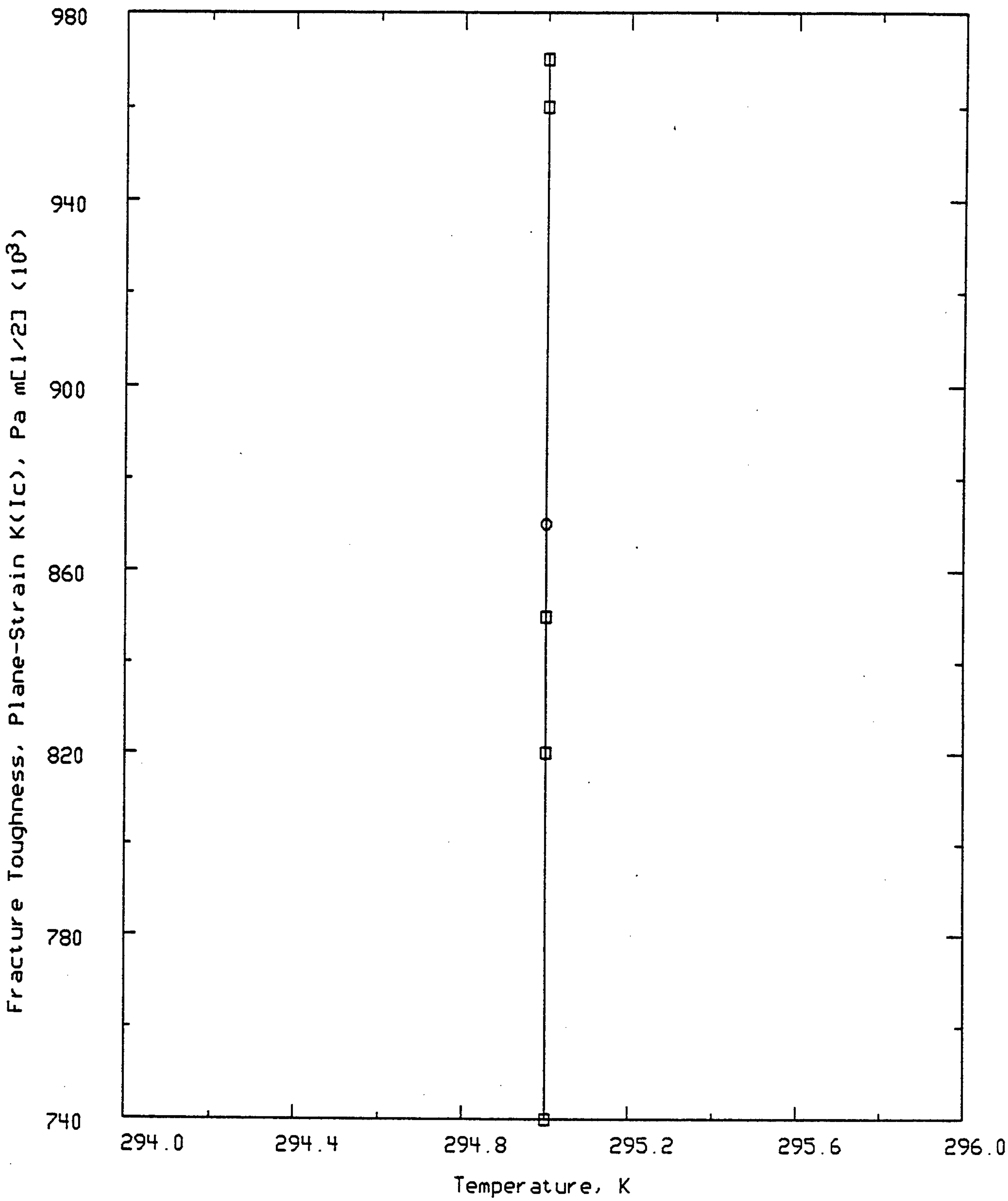

Figure 237 Fracture Toughness, Plane-Strain K(Ic) of Silicon

MATERIAL: Silicon | HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
PROPERTY: Fracture Toughness, Plane-Strain K(Ic) | DATA SET 238

****

Material Preparation

Crystal Growing Method :
Directional solidification casting

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :
Precursor cracks produced by Vickers indentor under 20N load directed into the tensile surface with indentor axes parallel to sample edges.
Flaw lengths were measured with SEM on fractured surfaces.

Material Microstructure

Grain Sizes: 0.3 to 3 mm perpendicular to growth direction
1 to 10 mm parallel to growth direction

Specimen Identification

Number/Name : Directionally Cast Polycrystalline Silicon
Dimensions (Geometry) :

Length	50.8	mm
Width	5.98	mm
Thickness	3.00	mm

Orientation With Respect To Material : Transverse Direction in T-S Plane

Measurement/Evaluation Method

Name/Description :
Four-Point Flexural Test on Pre-Indented Specimens
Major span distance was 40 mm and minor span was 19 mm

Measured/Evaluated Properties

X	: Temperature	K
Y	: Fracture Toughness, Plane-Strain K(Ic)	$Pa\ m^{1/2}$
Z1	: Flexural Strength	Pa

Data Points :

X	Y	Z1	Remarks:
2.950e+02	6.900e+05	8.810e+07	5 N Vickers indentor
2.950e+02	9.100e+05	6.640e+07	
2.950e+02	6.700e+05	4.950e+07	
2.950e+02	7.400e+05	6.940e+07	

2.950e+02	9.900e+05	7.520e+07	
2.950e+02	8.000e+05		Average: Stand Dev. = 17.7 %

Comments on Data

Crack propagation is along grains for this orientation. Since flaw size (typically 0.3 mm) is no larger than grain sizes, these fracture toughness results do not differ appreciably from single-crystalline silicon data.

Reference

FRACTURE OF DIRECTIONALLY SOLIDIFIED MULTICRYSTALLINE SILICON.
Chen, C. P. Leipold, M. H., Jr.
Helmreich, D.
J. AM. CERAM. SOC.
65, C-49, 1982.

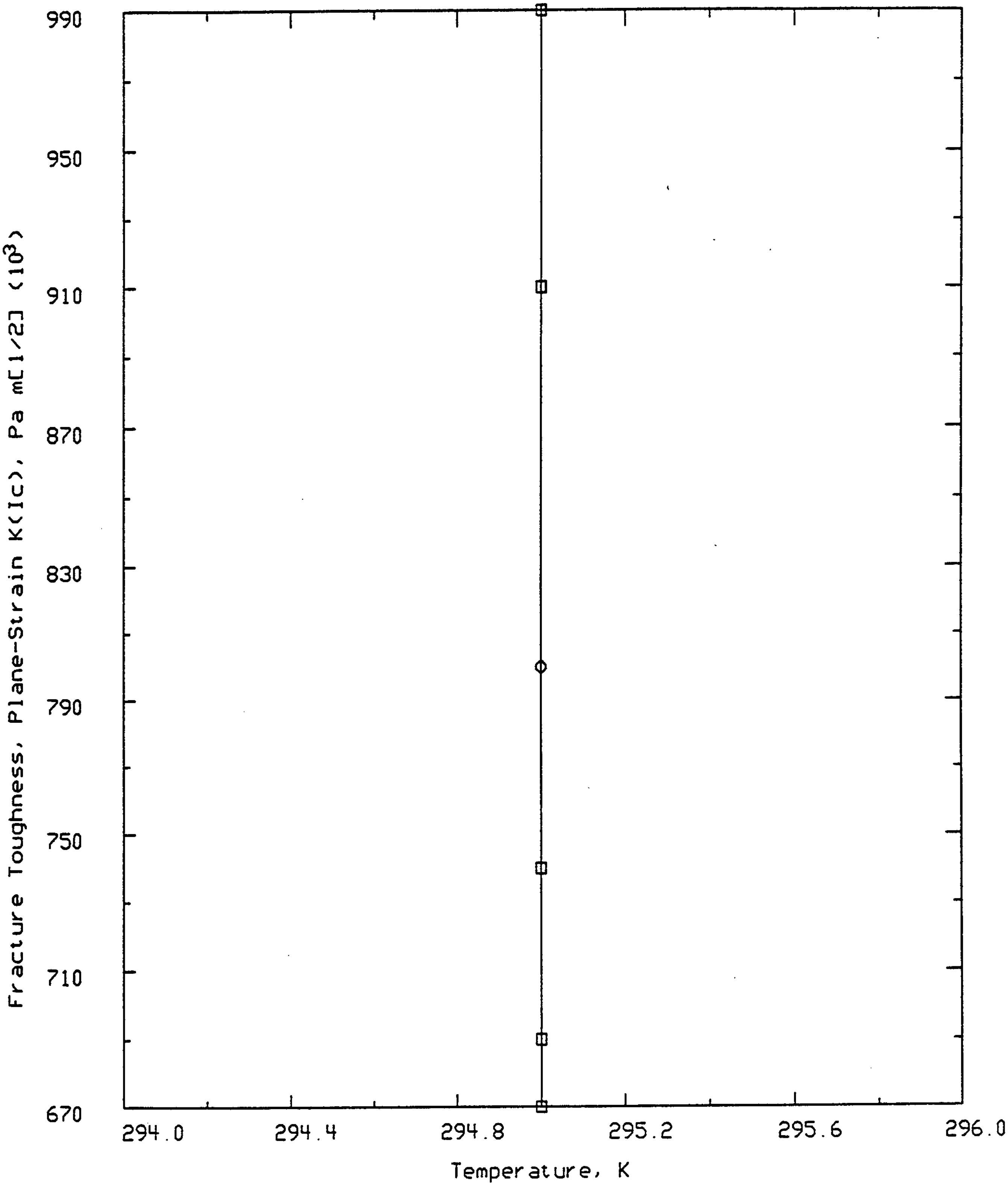

Figure 238 Fracture Toughness, Plane-Strain K(Ic) of Silicon

MATERIAL: Silicon

PROPERTY: Stress Intensity at Fracture

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 239

****

Material Preparation

Crystal Growing Method :
Czochralski, with ingot grown in <111> direction

Material Microstructure

Single-crystalline material

Specimen Identification

Orientation With Respect To Material : [111] Direction

Measurement/Evaluation Method

Name/Description :
Four-Point Flexure on Notched Specimen (Notch-Root Radius Effect)
Parameters-Textual :
Major span distance was 10.16 cm and minor span was 5.08 cm

Measured/Evaluated Properties

X	: Radius of Notch Tip (Root Radius)	m
Y	: Stress Intensity at Fracture	Pa $m^{1/2}$
Z1	: Flexural Strength	Pa
Z2	: Temperature	K

Data Points :

X	Y	Z1	Z2
8.000e-05	1.340e+06		2.950e+02
8.000e-05	1.580e+06		2.950e+02
8.000e-05	1.300e+06		2.950e+02
1.300e-04	1.240e+06		2.950e+02
1.500e-04	1.570e+06	1.180e+08	2.950e+02
1.500e-04	2.010e+06	1.500e+08	2.950e+02
1.500e-04	1.460e+06	1.120e+08	2.950e+02
1.800e-04	1.710e+06		2.950e+02
1.800e-04	1.810e+06		2.950e+02
1.800e-04	1.880e+06	1.420e+08	2.950e+02
1.800e-04	1.840e+06	1.420e+08	2.950e+02
5.600e-04	2.560e+06	1.170e+08	2.950e+02
5.600e-04	2.410e+06	1.100e+08	2.950e+02
5.800e-04	2.850e+06	1.300e+08	2.950e+02

Comments on Data

Average flexural strength was 128 MPa.
Stress intensity for small notch-root radius compares favorably with published fracture toughness data for silicon measured by blunt-notch indentation methods.

Reference

EFFECT OF NOTCH ROOT RADIUS ON THE FRACTURE BEHAVIOUR OF MONOCRYSTALLINE SILICON.
Myers, R. J. Hillberry, B. M.
FRACTURE 1977, ADVANCE IN RESEARCH ON THE STRENGTH AND FRACTURE OF MATERIALS, VOL. 3B-APPLICATIONS AND NON-METALS, INT. CONF. FRACTURE, ICF4
3B, 1001-5, 1977.
(Edited by D. M. R. Taplin; PERGANON PRESS: NEW YORK)

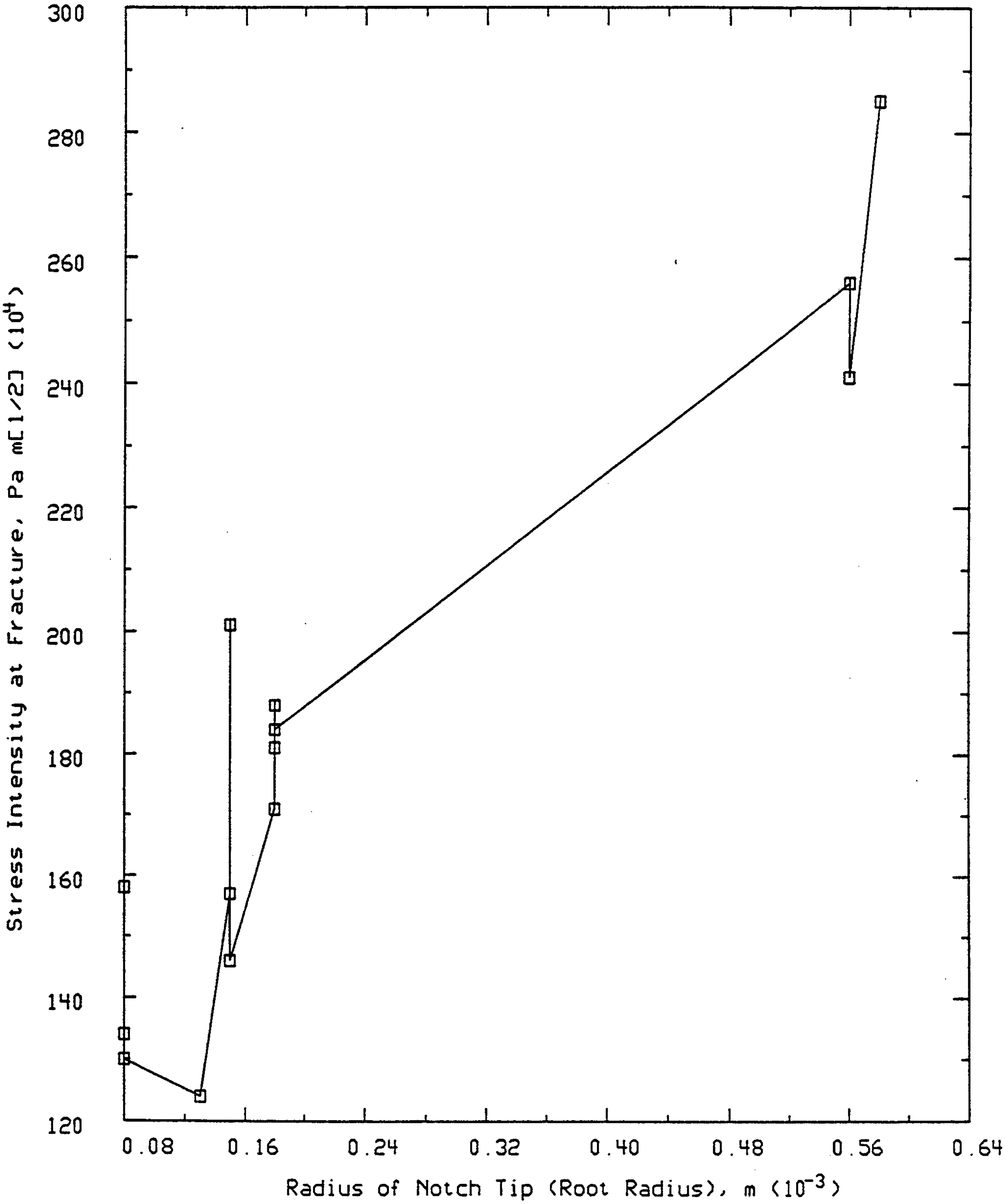

Figure 239 Stress Intensity at Fracture of Silicon

MATERIAL: Silicon: P doped	HTMIAC/CINDAS 1994
	PURDUE UNIVERSITY
PROPERTY: Surface Energy for Cleavage	DATA SET 240

****

Vendor/Producer/Fabricator

Philips Laboratories, North American Philips Corporation

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation

Descriptors-Textual :

The as-received 0.2 cm thick slabs had previously been polished to device-grade standards.
Specimens were cut with a diamond saw, polished, and etched to remove cutting damage.
Precursor cracks were produced by a spark discharge. Due to the high resistivity of silicon a silver film 1000 Angstroms thick was vapor-deposited to enable the spark discharge to occur. No evidence was observed for the presence of silver in the crater or precursor cracks as determined by microprobe analysis.

Material Microstructure

Single-crystalline material with dislocation density < 200 cm[-2].

Specimen Identification

Dimensions (Geometry) :

Length	15	mm
Width	5	mm
Thickness	2	mm

Orientation With Respect To Material : (110) Plane

Additional Properties

Electrical Properties :

Electrical Resistivity	0.14	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :

Tensile Fracture of Pre-Cracked Specimens
Precursor crack length on fracture surface was measured optically by using Nomarski interference contrast to highlight the crack front.

Parameters-Textual :

Instrom machine was employed with cross-head speed of 0.127 cm/min.

Measured/Evaluated Properties

X : Temperature — K
Y : Surface Energy for Cleavage — $J\ m^{-2}$

Data Points :

X	Y	Remarks:
2.930e+02	1.140e+00	Stand. Dev. = 0.15, (111) Crack Surfaces

Comments on Data

Fracture strength versus precursor-crack length for seven specimens was used to compute the surface cleavage energy for (111) crack surfaces.
The evidence indicated that the stress field at the precursor crack tip satisfied the Griffith criterion.

Reference

THE SURFACE ENERGY OF SILICON, GALLIUM ARSENIDE, AND GALLIUM PHOSPHIDE.
Messmer, C. Bilello, J. C.
J. APPL. PHYS.
52 (7), 4623-9, 1981.

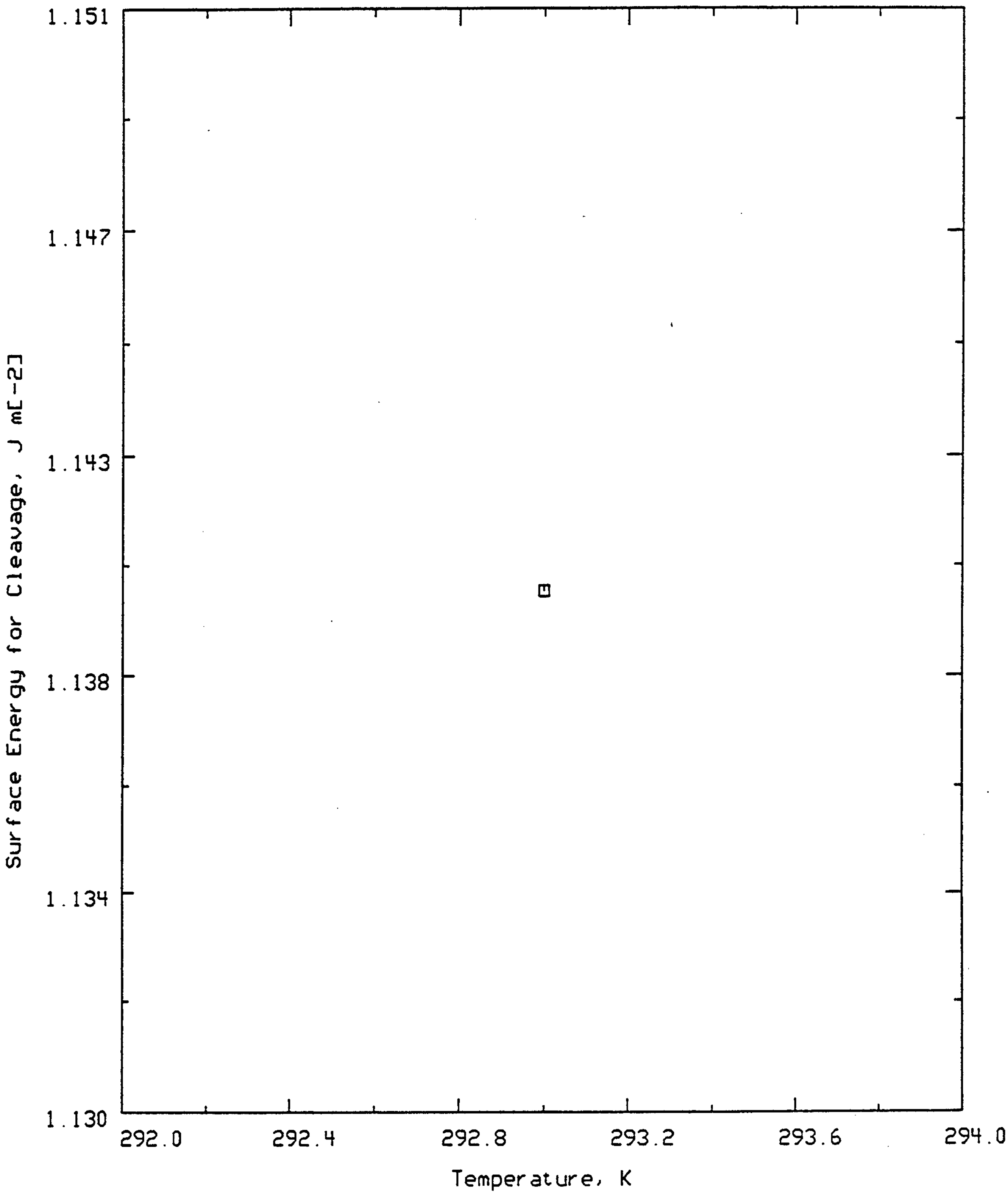

Figure 240 Surface Energy for Cleavage of Silicon: P doped

MATERIAL: Silicon: P doped

PROPERTY: Surface Energy for Cleavage

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 241

****

Vendor/Producer/Fabricator

Philips Laboratories, North American Philips Corporation

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation

Descriptors-Textual :

The as-received 0.2 cm thick slabs had previously been polished to device-grade standards.

Specimens were cut with a diamond saw, polished, and etched to remove cutting damage.

Precursor cracks were produced by a spark discharge. Due to the high resistivity of silicon a silver film 1000 Angstroms thick was vapor-deposited to enable the spark discharge to occur. No evidence was observed for the presence of silver in the crater or precursor cracks as determined by microprobe analysis.

Material Microstructure

Single-crystalline material with dislocation density < 200 cm[-2].

Specimen Identification

Dimensions (Geometry) :

Length	15	mm
Width	5	mm
Thickness	2	mm

Orientation With Respect To Material : (111) Plane

Additional Properties

Electrical Properties :

Electrical Resistivity	0.14	Ω cm
Temperature	295	K

Measurement/Evaluation Method

Name/Description :

Tensile Fracture of Pre-Cracked Specimens

Precursor crack length on fracture surface was measured optically by using Nomarski interference contrast to highlight the crack front.

Parameters-Textual :

Instrom machine was employed with cross-head speed of 0.127 cm/min.

Measured/Evaluated Properties

X : Temperature K
Y : Surface Energy for Cleavage $J\ m^{-2}$

Data Points :

X	Y	Remarks:
2.930e+02	1.900e+00	Stand. Dev. = 0.20, (110) Crack Surfaces

Comments on Data

Fracture strength versus precursor-crack length for six specimens was averaged to compute the surface cleavage energy for (110) crack surfaces.
Evidence indicated that the Griffith criterion for stress field at the precursor-crack tip was satisfied.

Reference

THE SURFACE ENERGY OF SILICON, GALLIUM ARSENIDE, AND GALLIUM PHOSPHIDE.
Messmer, C. Bilello, J. C.
J. APPL. PHYS.
52 (7), 4623-9, 1981.

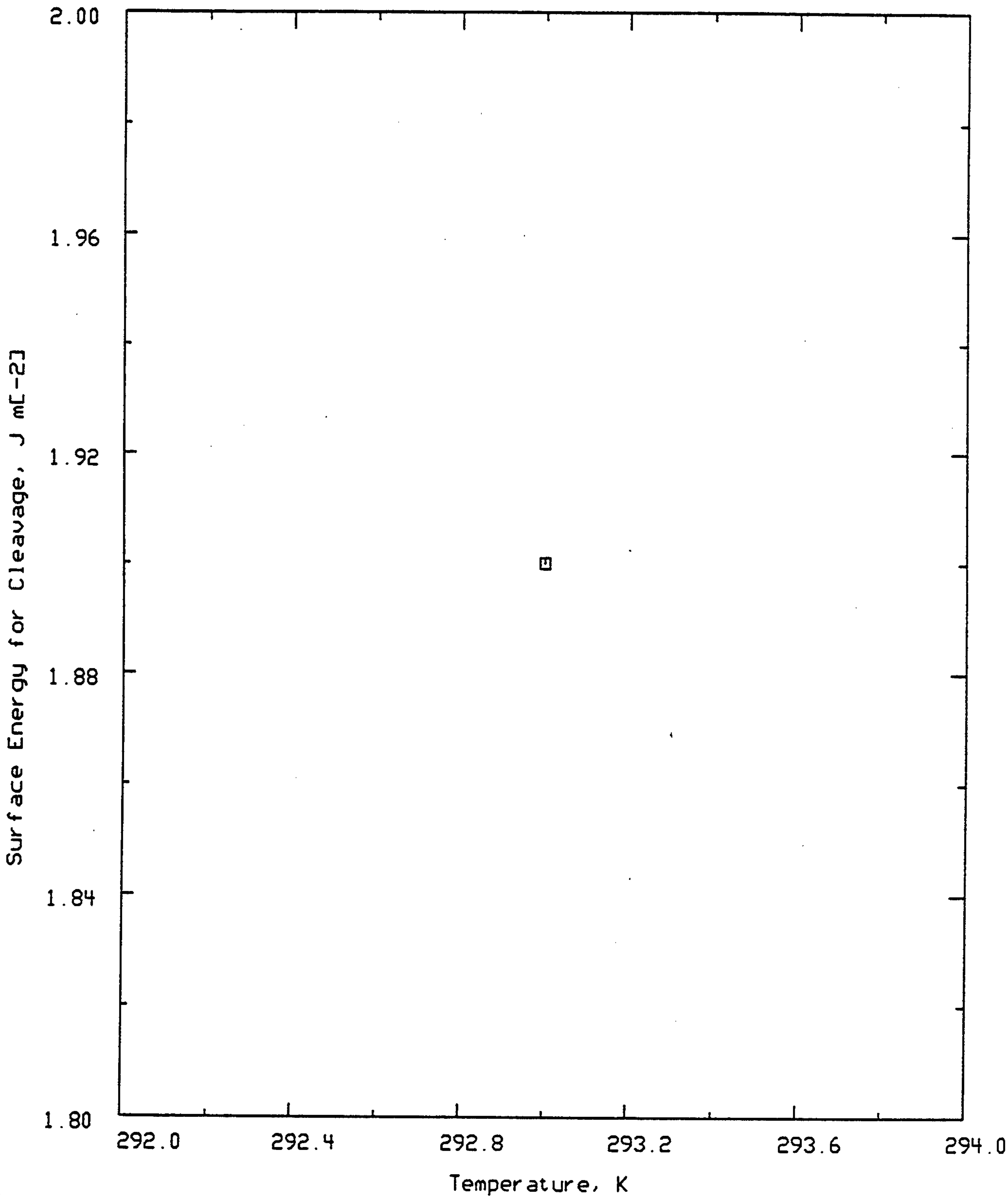

Figure 241 Surface Energy for Cleavage of Silicon: P doped

MATERIAL: Silicon, n-type

PROPERTY: Surface Energy for Cleavage

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 242

****

Vendor/Producer/Fabricator

Monsanto Company, St. Louis, Mo.

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation

Descriptors-Textual :

As-cut specimens were lapped with 600 grit silicon carbide and subsequently etched.

Precursor cracks were produced by scribing lines on the flat faces of the specimens.

Precursor cracks from L/3 to 2L/3 in length (L = specimen length) resulted in compliance being proportional to crack length.

Specimen Identification

Number/Name : Double-Torsion Specimen

Dimensions (Geometry) :

Length	25.4	mm
Width	6.4	mm
Thickness	0.38	mm

Additional Identifiers :

Specimen flat faces were {100} planes

Precursor crack planes were {110} planes

Additional Properties

Electrical Properties :

Electrical Resistivity	173+/-10	Ω m
Temperature	295	K

Measurement/Evaluation Method

Name/Description :

Double-Torsion Method

An Instron machine was fitted with a compression cage, a double torsion jig and a CM load cell.

Parameters-Textual :

A cross-head speed of 0.127 mm s[-1] was used.

Crack length was measured by optical microscopy on cleaved surfaces and the orientation was determined by the Laue back reflection method.

The theoretical model took elastic anistropy into account.

Measured/Evaluated Properties

X : Temperature K
Y : Surface Energy for Cleavage $J\ m^{-2}$

Data Points :

X	Y
2.950e+02	1.810e+00

Comments on Data

Fracture occurred in Mode I and was of type (110)[110].
The critical load value was 0.650 kg.
Critical stress intensity was 0.74 MN m[-3/2].
Critical energy release rate was 3.62 J m[-2].

Reference

FRACTURE SURFACE ENERGY DETERMINATION IN (110) PLANES IN SILICON BY THE DOUBLE TORSION METHOD.
Bhaduri, S. B. Wang, F. F. Y.
J. MATER. SCI.
21, 2489-92, 1986.

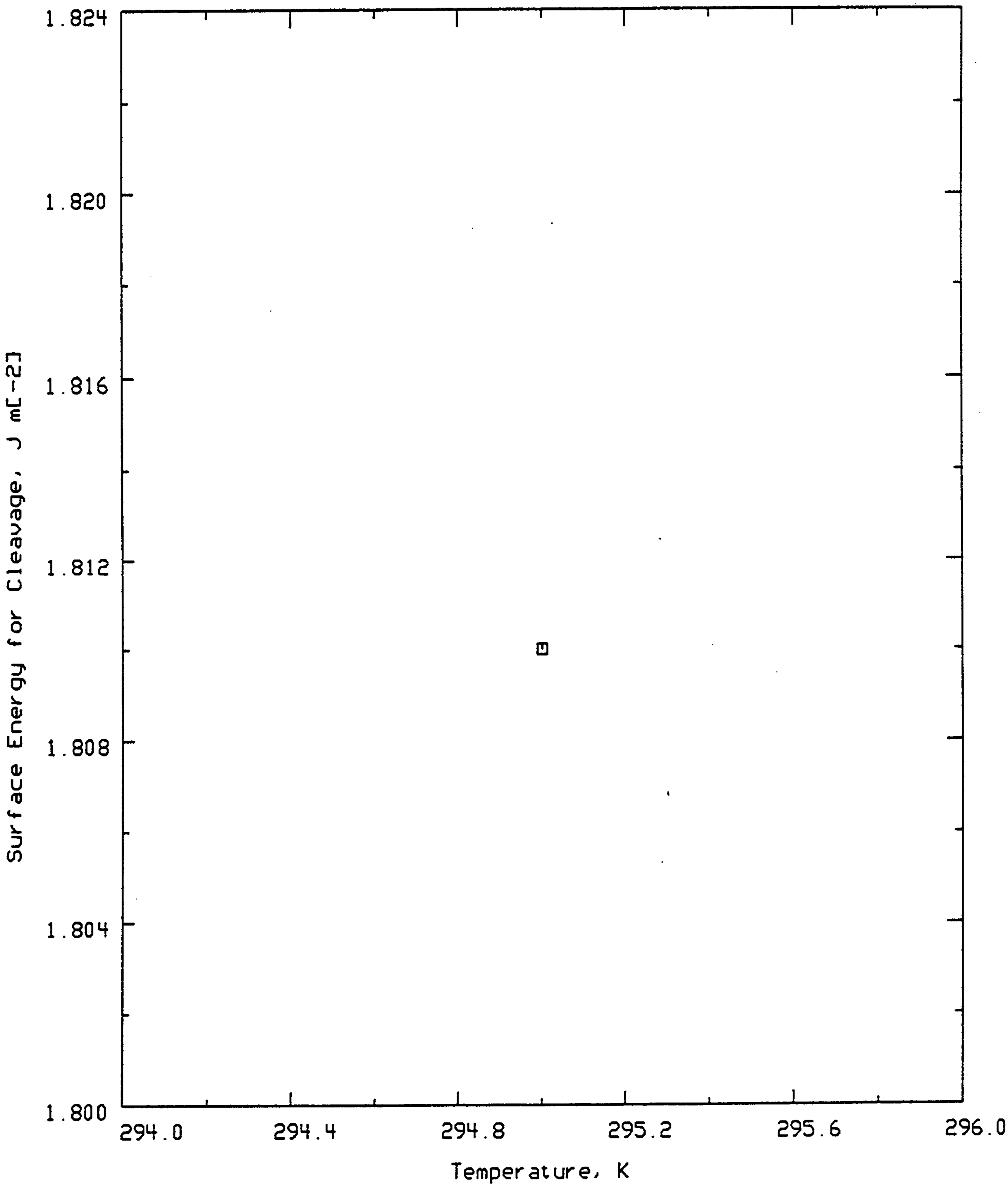

Figure 242 Surface Energy for Cleavage of Silicon, n-type

MATERIAL: Silicon

PROPERTY: Surface Energy for Cleavage

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY
DATA SET 243

****

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :
Polished and thinned slices were carefully cracked at one edge while rigidly clamping the slice.
Measurement specimen was cut from such a precracked slice.

Material Microstructure

Single-crystalline material

Measurement/Evaluation Method

Name/Description :
Double Cantilever Beam Using a Pre-Cracked Specimen
Tungsten-wire hooks were attached to each side of crack to apply force while the specimen was immersed into liquid nitrogen.
Parameters-Textual :
Loading was accomplished by adding links of a chain (1.7g/link) to the specimen.
Crack length was measured along the fracture surfaces using a traveling microscope.
Existing theory for double cantilever beams was used to analyse the data.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Surface Energy for Cleavage	$J\ m^{-2}$

Data Points :

X	Y	Remarks:
7.715e+01	1.220e+00	Specimen Number Si 2,(111) Crack Planes
7.715e+01	1.230e+00	Si 14
7.715e+01	1.230e+00	Si 15
7.715e+01	1.230e+00	Si 6
7.715e+01	1.235e+00	Si 10
7.715e+01	1.240e+00	Si 12
7.715e+01	1.250e+00	Si 5
7.715e+01	1.245e+00	Si 9
7.715e+01	1.250e+00	Si 7
7.715e+01	1.270e+00	Si 3
7.715e+01	1.270e+00	Si 8

7.715e+01	1.270e+00	Si 13
7.715e+01	1.280e+00	Si 4
7.715e+01	1.290e+00	Si 16
7.715e+01	1.300e+00	Si 1
7.715e+01	1.230e+00	Average for 15 specimens, (111) Crack Planes

Comments on Data

Since dissipative factors tended to increase the surface cleavage energy, any high values were excluded from the tabulations.

The crack surfaces were (111) planes in each case.

Reference

SURFACE ENERGY OF GERMANIUM AND SILICON.
Jaccodine, R. J.
J. ELECTROCHEM. SOC.
110 (6), 524-7, 1963.

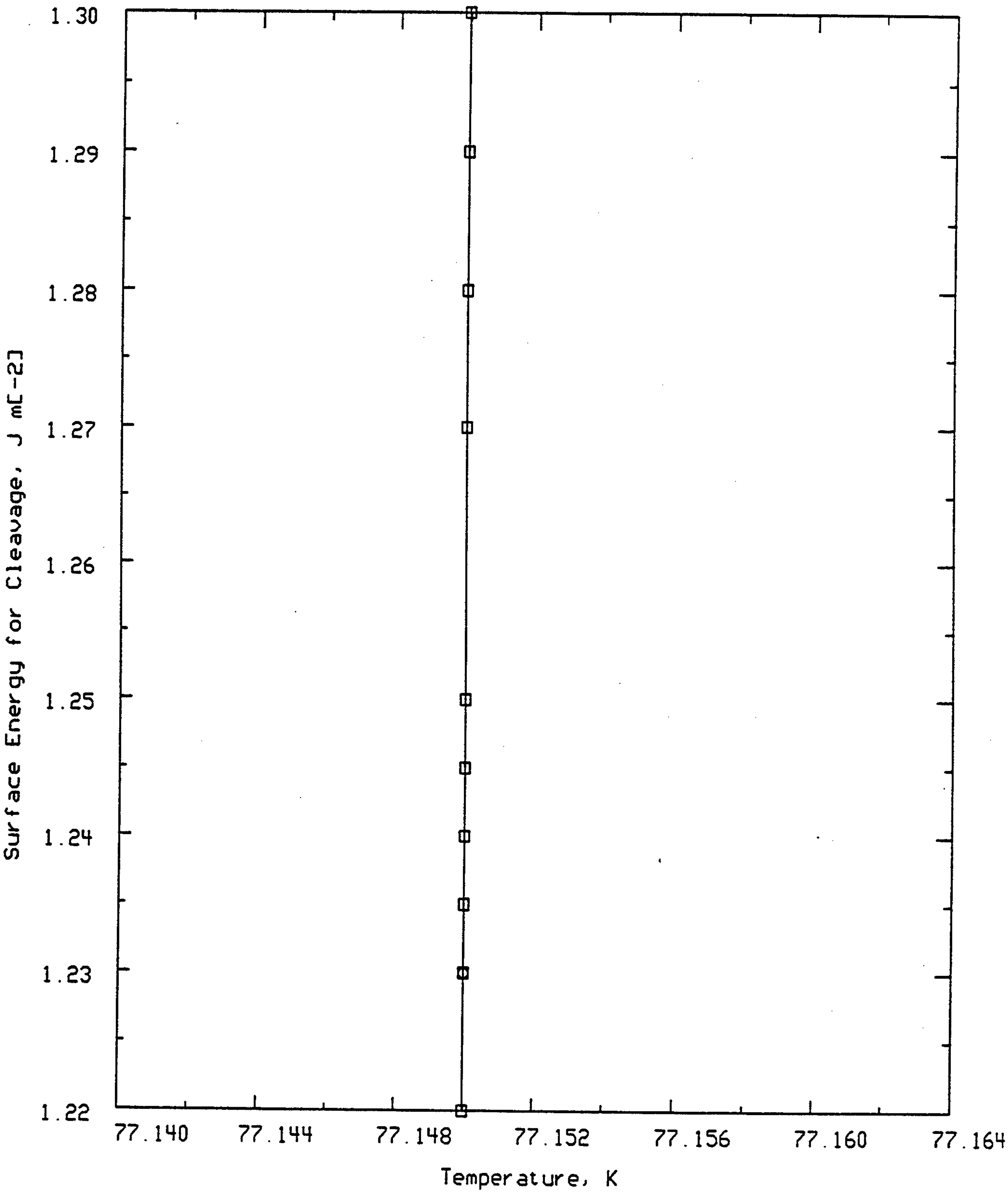

Figure 243 Surface Energy for Cleavage of Silicon

MATERIAL: Silicon

HTMIAC/CINDAS 1994
PURDUE UNIVERSITY

PROPERTY: Surface Energy for Cleavage

DATA SET 244

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Vendor/Producer/Fabricator

Semiconductor Products Department of General Electric Co.

Material Preparation

Crystal Growing Method :
Floating-zone

Additional Preparation/Conditioning

Conditioning/Preparation : Precursor Crack Generation
Descriptors-Textual :
Specimens were cut, slotted at one end, had holes bored for attachments, and chemically polished with HF + HNO(3).
Precursor crack was initiated by abrading the base of the slot.
Initial crack was started by using a knife blade jig immersed in liquid nitrogen.

Material Microstructure

Single crystals of semiconductor grade silicon

Specimen Identification

Number/Name : Specimen numbers S-10 and S-4.
Dimensions (Geometry) :

Length	8.5	mm
Width	2.20	mm
Thickness	2.84	mm
Length	10.1	mm
Width	3.10	mm
Thickness	1.93	mm

Additional Identifiers :
Specimen sides (one set) were {111} planes
Specimen length was along <112>.

Measurement/Evaluation Method

Name/Description :
Double Centilever Beam Using a Pre-Cracked Specimen.
Parameters-Textual :
A specially designed yoke attached to the specimen by pivot bearings was used to transmit force to the specimen.
An Instron testing machine was used with load applied at a rate of 8 gram/sec.
Critical loads for crack propagation correspond to loads

for which the crack length suddenly increased by some amount.
Crack length was measured by microscopic examination of the cleaved surfaces.
Surface cleavage energy was obtained from a theoretical modeling of critical crack growth.

Measured/Evaluated Properties

X	: Temperature	K
Y	: Surface Energy for Cleavage	$J\ m^{-2}$

Data Points :

X	Y	Remarks:
7.700e+01	1.250e+00	Specimen S-10
7.700e+01	1.230e+00	Specimen S-4
7.700e+01	1.240e+00	Average Value

Comments on Data

Cleavage surfaces were {111} planes.

Reference

DIRECT MEASUREMENTS OF THE SURFACE ENERGIES OF CRYSTALS.
Gilman, J. J.
J. APPL. PHYS.
31 (12), 2208-18, 1960.

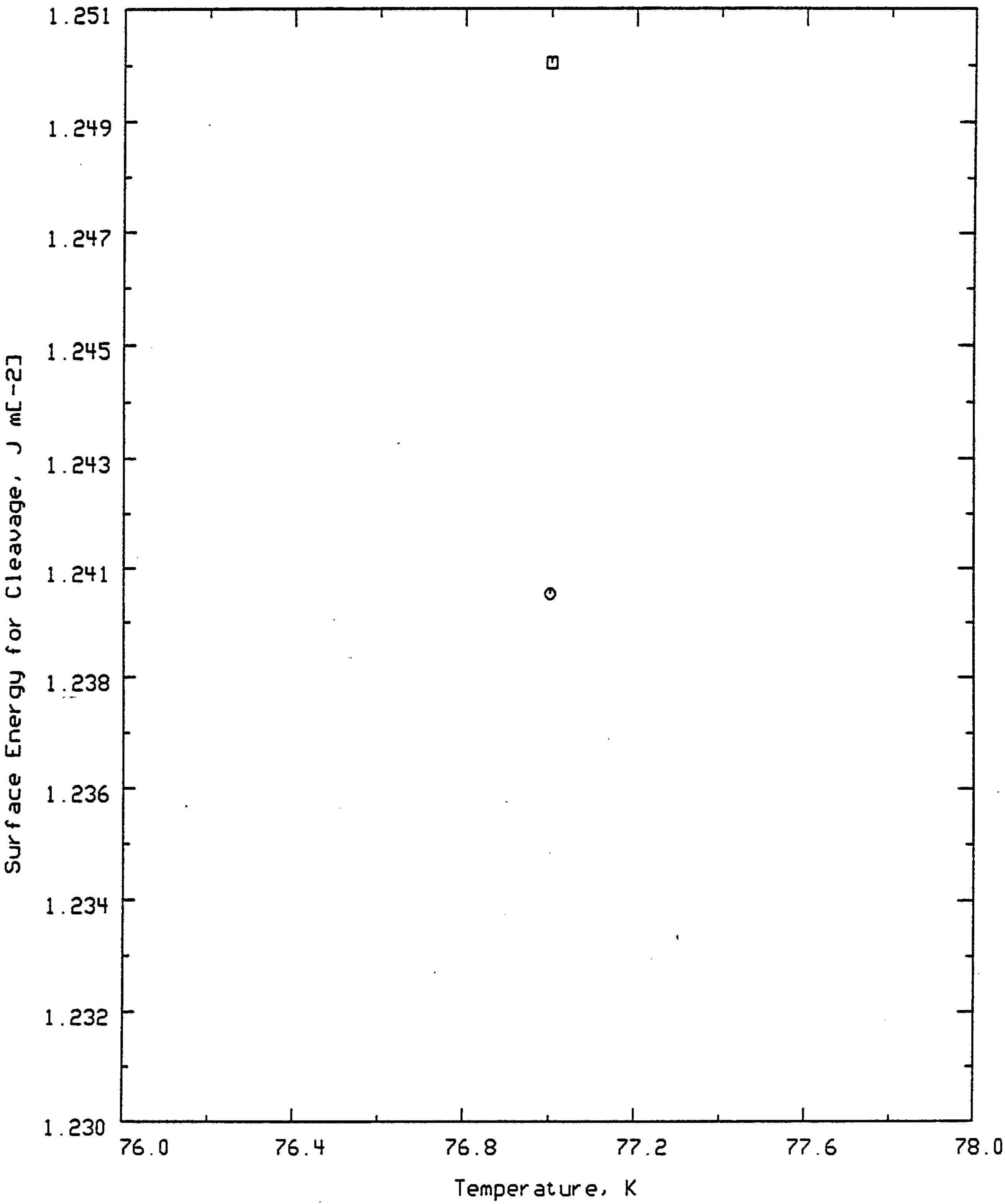
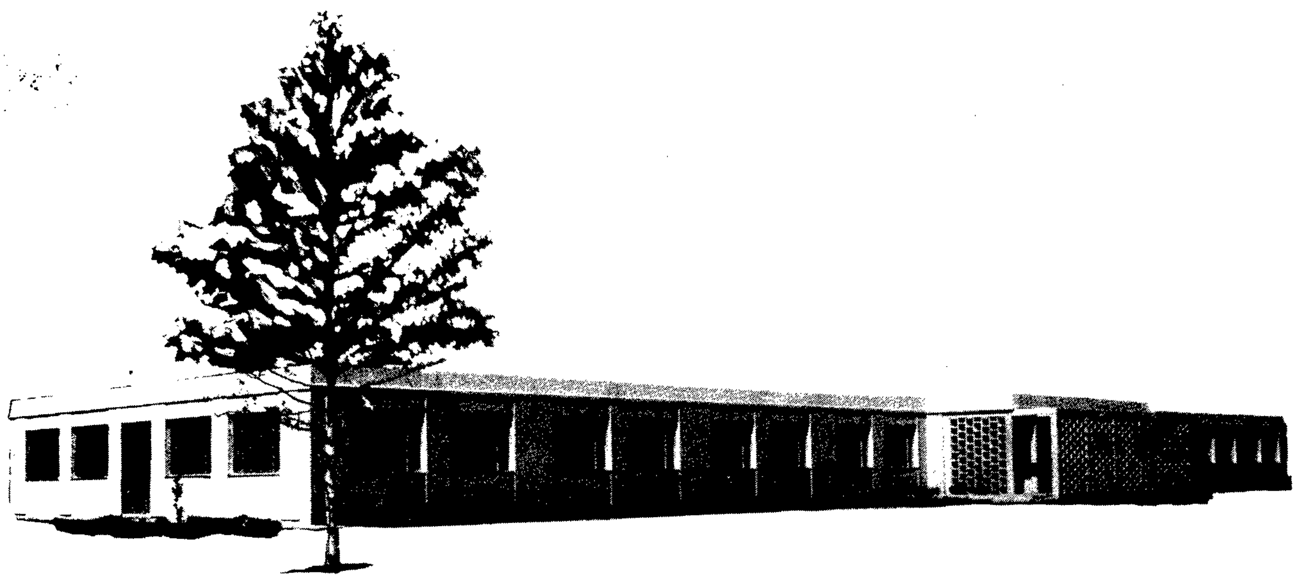


Figure 244 Surface Energy for Cleavage of Silicon



CENTER FOR INFORMATION AND NUMERICAL DATA ANALYSIS AND SYNTHESIS